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Vegetation maps:

- Cumberland Plain
- Peery Lake area

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Cunninghamia

A journal of plant ecology for eastern Australia

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COVER
Trees of *Eucalyptus moluccana* and *Eucalyptus tereticornis*, with *Bursaria spinosa* understorey in Cumberland Plain Woodland in the Woodland Conservation Area at Mount Annan Botanic Garden
Photographer: Jaime Plaza

Allan Cunningham, botanist and explorer (1791–1839)

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The native vegetation of the Cumberland Plain, western Sydney: systematic classification and field identification of communities

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Abstract: Twenty-two vascular plant communities occurring on, and adjacent to the Cumberland Plain and Hornsby Plateau, are defined using a multi-variate analysis of quantitative field survey data. Communities are described using structural features, habitat characteristics and diagnostic species. Diagnostic species are identified using a statistical fidelity measure. The pre–European spatial distribution of communities is estimated using a decision tree approach to derive relationships between community distribution and geological, climatic and topographical variables. Contemporary vegetation cover is estimated from 1:16 000 scale aerial photography (1997/98) and sorted into six categories based on cover of *Eucalyptus* species. These categories are only approximately related to vegetation condition: high *Eucalyptus* cover classes are most likely to contain high levels of floristic diversity, but areas with scattered cover or no cover at all may have either high or low diversity.

Map accuracy is assessed using independent field samples and is primarily limited by the accuracy of 1:100 000 geological maps. Patterns in overstorey composition were mapped at 1:16 000 scale but were less useful in delineating community boundaries than was hoped because few species are confined to a single community. The extent to which observer bias may influence estimates of the present extent of remnant vegetation is investigated by comparing the interpretations of two observers for a subset of the study area.

The community classification is interpreted in light of previous publications and the Endangered Ecological Communities listed under the NSW *Threatened Species Conservation (TSC) Act* (1995). Four communities listed under the *TSC Act* (1995) are represented by more than one unit in the new classification: *Cumberland Plains Woodland* (represented by Shale Plains Woodland, Shale Hills Woodland); *Sydney Coastal River Flat Forest* (Riparian Woodland, Riparian Forest, Alluvial Woodland); *Shale/Sandstone Transition Forest* (Shale/Sandstone Transition Forest low sandstone influence, high sandstone influence); and *Sydney Turpentine-Ironbark Forest* (Turpentine-Ironbark Forest, Turpentine-Ironbark Margin Forest). A further seven listed communities are described in this paper (*Cooks River/Castlereagh Ironbark Forest, Shale/Gravel Transition Forest, Castlereagh Swamp Woodland, Agnes Banks Woodland, Western Sydney Dry Rainforest, Moist Shale Woodland*, and *Blue Gum High Forest*).

As a result of clearing, native vegetation cover on the Cumberland Plain has been reduced to only 13.1% (± 1.7) of the pre-European extent. Despite high levels of fragmentation, the presence of exotic species and a history of extensive grazing, high numbers of native species were recorded in remnants of all sizes. A large proportion of species was recorded once only (22%), while nearly half of all species were recorded 5 times or less. This suggests that there is a high likelihood that further clearing will lead to a loss of floristic diversity. Two exotic species (*Olea europea* subsp. *africana* and *Myrsiphyllum asparagoides*) are identified as a major threat to the conservation of native flora due to their widespread distribution and ability to out-compete native species. Control of these species should be a high priority in conservation management.

***Cunninghamia* (2003) 8(1): 1–75**

Introduction

The composition of vascular plant communities is highly complex and variable because the abundance of individual species varies independently and continuously throughout the landscape (Austin 1985). The classification and mapping of species assemblages has proven to be a useful method for describing and interpreting these patterns (Mucina 1997). Classification units (communities) provide an obvious focus for efforts to conserve the diversity of biological assemblages. Under the NSW *Threatened Species Conservation (TSC) Act* (1995) an assemblage of species at risk of extinction may be listed as an Endangered Ecological Community (EEC). However, because communities are abstract by nature and inconsistently delineated, the compilation of precise descriptions for legal purposes is problematic.

Descriptions of EECs listed under the *TSC Act* are compiled from a range of sources and typically contain notes on the distribution, structure and habitat occupied by the community and a list of characteristic species. Because there is limited scope for the inclusion of contextual information (such as the relationship between the listed EEC and other communities in the area, and the relative abundance, frequency and fidelity of characteristic species) EEC descriptions may not be optimal for delineating communities in the field in all circumstances. Supporting contextual data in the form of regional vegetation maps and descriptions can assist in the interpretation of EEC determinations.

Most of the native vegetation communities of the Cumberland Plain and neighbouring Wianamatta Shale are listed under the *TSC Act*. Due to the rate of urban development to the west of Sydney there is a large potential for development proposals to significantly impact on listed communities. Hence there is a need for quantitative data to assist the identification of communities and the assessment of the conservation value of remnants. Quantitative community descriptions would provide a means for differentiating between communities, particularly those not recognised in previous vegetation surveys. An estimate of the extent of native vegetation remaining is also required for the assessment of conservation significance and conservation planning.

This paper describes a new survey of vegetation communities occurring on the Cumberland Plain and isolated and less extensive Wianamatta Shale soils on the adjacent plateaus. The survey incorporated: (i) systematic, stratified field sampling to record floristic structure and composition; (ii) a classification procedure based on hierarchical, agglomerative clustering analysis; (iii) spatial modelling of community distributions using geological, climatic and topographic variables on a 25 m grid; and (iv) the interpretation of patterns in canopy composition and remnant condition in aerial photographs. The use of these techniques in combination has recently been demonstrated in the South East Forests of NSW (Keith & Bedward 1999). The approach was applied on the Cumberland Plain with the following aims:

- revise the existing classification to take account of recently described communities and other communities warranting recognition;
- provide quantitative data for characteristic species in each community (frequency of occurrence and relative abundance);
- identify species showing high fidelity to each community as a basis for diagnosing community type in the field;
- estimate the present cover of native vegetation;
- derive a spatial model as a basis for predicting the vegetation type and conservation value of all remaining remnants.

Study area

Location and landform

The study area (Figure 1) was located in western Sydney (33°30–34°30 S, 150°30–151°30 E) and was formally defined as the extent of soils derived from three main geological units: Wianamatta group shales, Tertiary alluvium and Holocene alluvium (in areas draining Wianamatta group shales); (Walker 1960, Chapman & Murphy 1989, Bannerman & Hazelton 1990). This area includes the Cumberland Plain, a large central section of the Hornsby Plateau and the north-west margin of the Woronora Plateau (Bannerman & Hazelton 1990). West of Parramatta, the Cumberland Plain forms an elongated ellipse stretching from Sackville in the north to Thirlmere in the south, with the western boundary marked by the monocline of the Blue Mountains to the west of Penrith. East of Parramatta the Plain is truncated by the Hornsby Plateau in the north and the Woronora Plateau to the south, and finally terminates near the city centre.

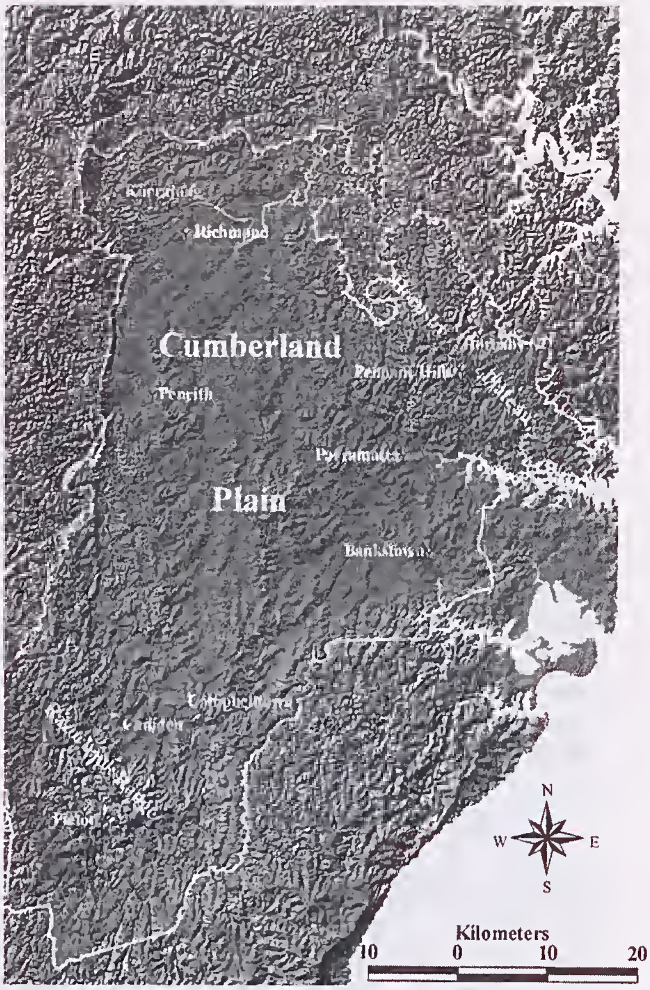

Fig. 1. The location of the study area, showing the physiographic contrast between the Cumberland Plain and the surrounding plateaus of the Sydney Basin.

The Cumberland Plain comprises gently undulating plains and low hills, rising gradually from the flat, low lying areas just above sea level in the north to an altitude of around 350 m on the rolling hills of the Razorback Range in the south. Two low ridgelines project northward from this elevated southern region as far as Mount Druitt and Orchard Hills respectively. The eastern ridge forms a watershed between the drainage channels flowing north to the Hawkesbury River and those draining east into the Georges River. Separating the two ridges is the upper catchment of South Creek, which forms the major drainage channel of the Plain. Rising gradually to the north-west of the Plain, the broadly dissected Hornsby Plateau lies between 100 to 200 m above the northern half of the Plain. On the Hornsby Plateau, Wianamatta Shale soils are located predominantly along three broad ridgelines running approximately north-west from North Sydney to Hornsby and from Ryde to Castle Hill, and north from Castle Hill to Arcadia. Communities occurring on shale caps on the Blue Mountains and Bell Ranges (west of the study area) were not described in this study.

Geology and soils

The geology and soil landscapes of the study area have been described by Chapman and Murphy (1989), Hazelton et al. (1990) and Bannerman and Hazelton (1990); from which the following description was drawn. The oldest geological units outcropping within the study area are of sedimentary origin and were laid down during the middle Triassic period. Of these, the Wianamatta group is the dominant feature and occurs throughout the Cumberland Plain and on plateau tops and ridges on the Blue Mountains and Hornsby plateaus. It comprises claystone, siltstone, laminite and fine to medium-grained lithic sandstone weathering to low fertility soils ranging in texture from loam to heavy clay. The Wianamatta group conformably overlies the discontinuous Mittagong Formation and Hawkesbury Sandstone. The former comprises inter-bedded and laminated, fine to medium-grained quartz sandstone and siltstone, and constitutes passage beds between the Wianamatta Group and the Hawkesbury Sandstone. Hawkesbury Sandstone weathers to form sandy–loam soils of very low fertility. The Mittagong Formation and Hawkesbury Sandstone outcrop on the margins of the study area especially along watercourses where the overlying shale has eroded during the development of a streambed.

On the Cumberland Plain, the Wianamatta group is overlain by unconsolidated sediments deposited in two geological periods. The deposition and reworking of silty-clayey sands and gravels along watercourses has been ongoing throughout the Quaternary period. These constitute some of the most fertile soils of the Plain and are particularly extensive on the floodplains of the Hawkesbury–Nepean River in the north of the study area. Sediments dating from the Tertiary Period occur in two main localities: to the south of Richmond in the north-west part of the study area and south of Liverpool in the south-east. These comprise sand, clay, gravel and volcanic breccia of both colluvial and alluvial origin and give rise to soils of low fertility. In the vicinity of Agnes Banks tertiary sediments are overlain by low parallel dunes of quartz sand eroded from the upper catchment of the Hawkesbury–Nepean and deposited by wind during the quaternary period. These sandy soils are of very low fertility.

Vegetation and land use

The physiographic division between the Plain and the surrounding plateaus is paralleled by a stark contrast in the composition of native plant communities. The sandstone plateaus support heath, woodland and forest communities characterised by a diverse, sclerophyllous shrub layer and share few species in common with the grassy woodlands of the Cumberland Plain. Variation in the composition of plant communities on the Cumberland Plain was described by Pigeon (1941), who differentiated the *Eucalyptus moluccana – Eucalyptus tereticornis* and the *Eucalyptus saligna – Eucalyptus pilularis* associations along a gradient of increasing rainfall and also noted the occurrence of ecotones between shale and sandstone soils. Building on this work, Phillips (1947) described associations specific to alluvial soils of recent and Tertiary origin. Benson (1992) further elucidated the relationships between vegetation communities and underlying geology and compiled detailed descriptions of the composition and extent (both contemporary and pre-European) of native vegetation of the Penrith 1:100 000 map sheet. Numerous published and unpublished reports describe native vegetation remnants for localities within the Cumberland Plain, including Agnes Banks (Benson 1981) and Bents Basin (Benson et al. 1990). In the most recent comprehensive survey, NPWS (1997) compiled an inventory and description of native vegetation remnants of conservation significance for each local government area in western Sydney. This paper revises an unpublished survey report (NPWS 2000).

As a result of its topographic and geological characteristics, the Cumberland Plain has a much higher capability to support agricultural and urban land use activity than the surrounding plateaus (Bannerman & Hazelton 1990). Agricultural development was under way as early as 1792, by which time some 613 ha of land were under cultivation in the Parramatta–Toongabbie area (Phillip 1978). By 1810, the combined area under cultivation in Parramatta and Hawkesbury had grown to almost 29 000 ha (Bligh & Macquarie 1979), approximately 42% of the present area dedicated to agricultural production (University of Western Sydney 2000). By the mid- nineteenth century the majority of the Cumberland Plain was either under cultivation or subject to grazing. Urban expansion into western Sydney has been ongoing since European settlement, and has accelerated in the second half of the twentieth century (Benson & Howell 1990). In the year 2000, the suburbs of western Sydney held an estimated 20% of the population of NSW and were the predicted centre for 30% of the states future population growth (University of Western Sydney 2000). It is estimated that less than 5% of the pre-European vegetation coverage of the Cumberland Plain remains uncleared (NPWS 1997). In contrast, the vegetation of the surrounding sandstone plateaus is represented in large National Parks including Ku-ring-gai Chase, Blue Mountains and Royal National Parks.

Climate

Topography and distance from the coast are the primary determinants of weather patterns in the study area (Bureau of Meteorology 1979). Average annual rainfall is highest on the coast and decreases steadily inland as a result of moist air streams flowing predominantly from the east (Table 1). West of Parramatta, the majority of the Cumberland Plain receives less than 800 mm annually. Annual rainfall increases with elevation to approximately 900 mm on the margins of the Plain, and reaches a maximum of 1444 mm at Pymble on the Hornsby Plateau. Seasonal variation in rainfall is highest on the coast with wetter periods occurring in February–March (under the influence of easterly air streams) and June (southerly air streams). Further inland, rainfall is more evenly distributed, although the whole region experiences a relatively dry period in spring.

Table 1. Rainfall, temperature and frost statistics for selected weather stations on the Cumberland Plain and Hornsby Plateau.

B: Bankstown (eastern Plain); **P:** Parramatta (central Plain);
Pic: Picton (southern Plain); **R:** Richmond (northern Plain);
PH: Pennant Hills (Hornsby Plateau)

	B	P	Pic	R	PH
Annual Rainfall (mm)	921	922	804	806	1102
Av. min. Temp. July (°C)	3.1	4.6	1.8	3.6	4.6
Av. max.Temp. Jan. (°C)	27.7	28.1	29.5	29.4	27.6
No. days where Temp. >38°C (average/year)	–	–	6.1	9.6	–
Number of severe frost days (average/year)	46	38	133	84	85
Latest recorded severe frost in any year	31 Au	3 Sep	9 Oct	26 Sep	18 Sep

Average maximum temperatures in the hottest month (January) are lowest on the coast due to the frequency of on-shore winds (Table 1). Maximum temperatures increase westward as the influence of these winds dissipates, reaching a maximum on the central Cumberland Plain before decreasing with increasing elevation toward the margins of the Plain. Average minima for the coldest month (July) are highest on the coast and decrease steadily inland away from the moderating influence of the ocean. Temperature extremes occur more frequently with increasing distance from the coast. Frosts also occur more frequently away from the coast and at higher elevations, although the incidence and severity vary considerably over a small scale as a function of topographic, vegetation and soil related factors. Indicative climatic data for selected weather stations on the Cumberland Plain and Hornsby Plateau (Table 1) were sourced from the Bureau of Meteorology (1979).

Methods

The methods used in this study followed the approach used by Keith and Bedward (1999) and comprise the following components: (i) field sampling; (ii) cluster analysis and community classification; (iii) community description; (iv) describing environmental relationships and deriving a spatial model; (v) accuracy assessment; (vi) mapping of woody vegetation; and (vii) map compilation (Figure 2).

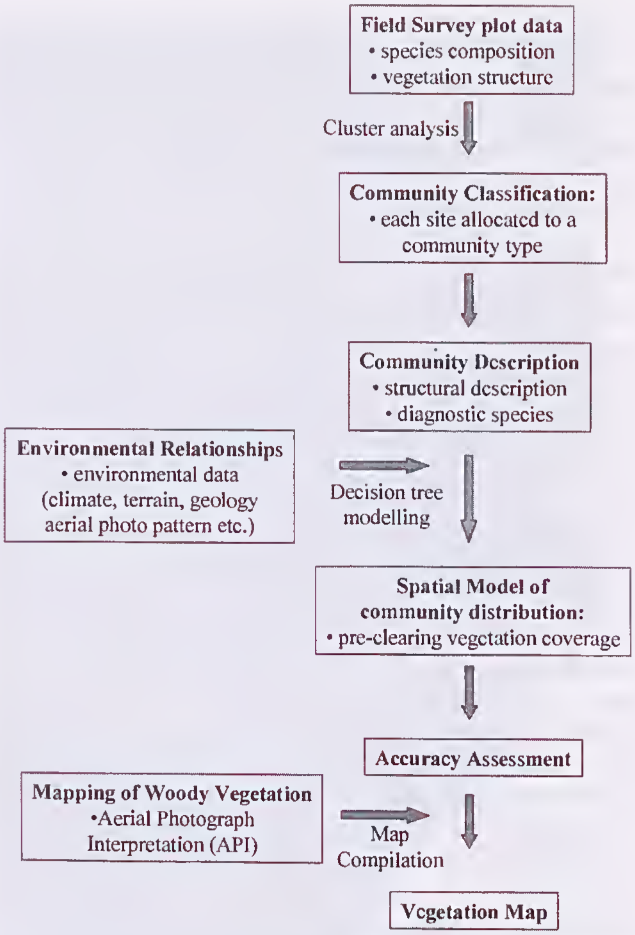
Field Survey plot data
• species composition
• vegetation structure
Cluster analysis
Community Classification:
• each site allocated to a community type
Community Description
• structural description
• diagnostic species
Environmental Relationships
• environmental data (climate, terrain, geology aerial photo pattern etc.)
Decision tree modelling
Spatial Model of community distribution:
• pre-clearing vegetation coverage
Accuracy Assessment
Mapping of Woody Vegetation
•Aerial Photograph Interpretation (API)
Map Compilation
Vegetation Map

Fig. 2. A summary of the major components of the survey: the sequence in which components were completed is indicated by the arrows.

Field sampling

Survey sites were stratified using factorial combinations of substrate, temperature and rainfall across the study area. Five geological substrates were included: Wianamatta Shale, Holocene alluvium (draining shale soils), Tertiary alluvium, estuarine sediments and aeolian deposits (*sensu* Bannerman & Hazelton 1990). Variation in temperature was characterised using the maximum temperature in the hottest month (January) and simplified into three zones representing ranges 26.1–27.0°C, 27.1–28.0°C, and 28.1–29.0°C. Annual rainfall was divided into four zones representing ranges 701–800 mm; 801–900 mm; 901–1000 mm; and 1001–1100 mm. Some combinations were not represented in the study area and others were poorly sampled due to the small area of remnant vegetation present in those strata.

Field sampling was carried out between October 1998 and September 2000. The vegetation at each survey site was described within a quadrat of area 0.04 ha. Quadrats were marked out using tape measures in an area representative of the surrounding vegetation and as far as possible away from areas of weed infestation or soil disturbance (sites were only located in remnants dominated by native species and highly disturbed or weed infested areas were not sampled). Where possible, several quadrats were used to sample local variation in slope, aspect and landform (e.g. gullies and ridges). Quadrats were square in shape except where a rectangular configuration was required to ensure homogeneity of terrain and soils across the plot.

All vascular plant species rooted within the quadrat were recorded and assigned a cover/abundance score using a modified Braun-Blanquet scale (Poore 1955) as follows:

1 = rare, few individuals present, cover < 5%;
2 = uncommon & cover < 5%;
3 = common & cover < 5%;
4 = (very abundant & cover < 5%) or (5% ≤ cover < 20%);
5 = (20% ≤ cover <50%);
6 = (50% ≤ cover <75%);
7 = (75% ≤ cover < 100%).

The height range and projected foliage cover were estimated for each of four structural strata (tree, small tree, shrub and forb), where recognisable at the site. A compass and clinometer were used to measure the slope and aspect at the centre of the quadrat, as well as horizon elevations at azimuths of 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°. The location and elevation of the site were determined in the field using 1:25 000 topographic maps and/or a geographic positioning system. The soil type was determined by hand-texturing. Evidence of rock out-cropping, erosion, weed invasion, logging, soil disturbance or recent fire was noted.

Plant species that could not be identified in the field were collected for later identification. Where necessary, collections were compared to specimens held at the National Herbarium of NSW to confirm their identity. Specimens that could not be identified to species level were not included in the analysis. Nomenclature was standardised to follow Harden (1990–1993). In many cases species recognised at the subspecies level were identified only to the species level. Published species lists (Benson et al. 1996, James et al. 1999) were consulted to determine the number of subspecies recorded for the study area. If only one subspecies had been recorded then the subspecific epithet was adopted. If two or more subspecies had been recorded then subspecies were pooled for analysis. The species name used in the community descriptions indicates the taxonomic level used in the analyses. Exotic species were recorded but excluded from classification analysis.

Cluster analysis and community classification

Data analysis was performed on the raw cover/abundance scores using the PATN package (Belbin 1991). Dissimilarity among survey sites was computed using a symmetric form of the Kulczynski coefficient (Faith 1991). Hierarchical agglomerative clustering was performed using a flexible unweighted pair group arithmetic averaging strategy with no adjacency constraint and a BETA value of -0.1. Homogeneity analysis (Bedward et al. 1992) was used to determine the point in the hierarchy at which a decline is observed in the rate of increase in within-group homogeneity yielded by further group subdivision. Visual inspection of the hierarchical dendrogram confirmed the integrity (*sensu* Belbin 1991) of the groups defined at this point, thus amalgamation was not considered. Groups containing clusters of high integrity were identified for possible subdivision. In addition, the preliminary groupings were compared to a previously derived floristic classification for the survey area to identify sub-groups corresponding to previously recognised communities (Benson 1992). Subdivision was carried out by systematically increasing the number of groups across the whole dendrogram. This process was continued only while an increase in the group number lead to the separation of sub-groups of high integrity, and ceased when groups of high integrity became split. When the definition of groups was completed, the analysis was repeated using the Bray-Curtis coefficient of dissimilarity (Clarke 1993) to examine the consistency of the grouping. The classification of each site was compared to that of the five nearest neighbours to check for potential misclassifications. Sites that could not be reliably assigned to a group were omitted.

Community descriptions and field identification

The floristic assemblages derived by cluster analysis were compared to community descriptions contained in recent publications on the vegetation of the survey area (Benson & Howell 1990, Benson 1992, NPWS 1997), as well as descriptions of EECs. Where an assemblage was judged to represent a previously described community, the assemblage was given the name in common use for that community. If an assemblage was judged not to have been previously described then a name was constructed using elements of the vegetation structure, topographical and geological preferences of the assemblage (e.g. Shale Hills Woodland).

Structural descriptions were compiled from the survey site data. The maximum height and projected foliage cover for each stratum were averaged across all sample sites representative of the community. The frequency with which each stratum was encountered in the community was also calculated. Summary statistics (mean, standard deviation and range) for the sample sites were calculated for elevation, slope, annual rainfall, ruggedness (900 m neighbourhood), solar radiation (January) and maximum temperature (January). The frequency with which sample sites were located on different substrates was also calculated.

Lists of diagnostic species were derived for each vegetation community to assist in the identification of communities in the field. Diagnostic species were those with a higher probability of occurring in the target community than expected based on their frequency of occurrence in the data set. For each community, an estimate was made of the minimum number of diagnostic species expected in any sample of the community (95% confidence interval). Using this estimate, map users may confirm (with 95% confidence) the identity of a vegetation community of unknown identity by enumerating the number of diagnostic species occurring in a field sample.

The identification of diagnostic species was based on an adaptation of the method proposed by Bruelheide (2000). A probability threshold was determined by an iterative process in which the underlying distribution was varied to maximise the number of diagnostic species represented in an independent set of samples of known classification. This process identified the hypogeometric distribution with a probability of 0.001 as the optimal threshold. Therefore, species were identified as positive diagnostic if their frequency of occurrence in the target community was higher than their frequency across the whole data set, and less than 0.1% likely to have occurred by chance alone. Species with target community frequency ≥ 0.4 (and not identified as positive diagnostic) were identified as constant species (characteristic of the target class as well as other classes). In order to minimise the inclusion of unreliable species, those with target class frequency < 0.2 and class frequency coefficient of variation > 0.05 were classed uninformative.

The same approach was used to identify exotic species showing an association with particular community types (positive diagnostic species) or frequently occurring across a range of community types (constant species). Patterns in weed invasion and native species diversity within remnants were investigated by correlating counts of exotic/native species in survey sites with remnant size and configuration (perimeter/area ratio) and the position of the survey within the remnant (distance to the remnant edge).

Table 2. Spatial data layers used in modelling the distribution of vegetation communities

Variable	**Description**
Parent geology	Geological formation responsible for surface soil features
Soil landscape	Integratedsoil/topography classes (Bannerman & Hazelton 1990)
Distance to sandstone (1)	Shortest distance to soils derived from sandstone, Mittagong Formation excluded (metres)
Distance to sandstone (2)	Shortest distance to soils derived from sandstone, Mittagong Formation included (metres)
Distance to coast	Shortest distance the nearest point of the coastline (metres)
Distance to stream	Shortest distance to stream of any size (metres)
Distance to stream (456)	Shortest distance to stream of size order 4 or larger (metres)
Easting	Australian Map Grid Easting, Zone 56
Northing	Australian Map Grid Northing, Zone 56
Elevation	Elevation above sea level (metres)
Aspect	Deviation from grid north of the horizontal component of the slope vector
Slope	Inclination from horizontal (degrees)
Topographic position	A measure of the position of each grid cell on a continuum between ridge (value = 100) and gully (value = 0) (after Skidmore 1990)
Annual rainfall	Annual Rainfall (mm)
Wetness	Continuous index representing the volume of water draining to a given location (after Moore et al. 1993)
Ruggedness (900 m)	Standard deviation of elevation of cells within a neighbourhood of 900 by 900 metres
Ruggedness (700 m)	Standard deviation of elevation of cells within a neighbourhood of 700 by 700 metres
Ruggedness (500 m)	Standard deviation of elevation of cells within a neighbourhood of 500 by 500 metres
Ruggedness (300 m)	Standard deviation of elevation of cells within a neighbourhood of 300 by 300 metres
Ruggedness (100 m)	Standard deviation of elevation of cells within a neighbourhood of 100 by 100 metres
Terrain (900 m)	Difference in elevation between an individual cell and the mean elevation of cells in the surrounding neighbourhood of 900 by 900 metres
Terrain (700 m)	Difference in elevation between an individual cell and the mean elevation of cells in the surrounding neighbourhood of 700 by 700 metres
Terrain (500 m)	Difference in elevation between an individual cell and the mean elevation of cells in the surrounding neighbourhood of 500 by 500 metres
Terrain (300 m)	Difference in elevation between an individual cell and the mean elevation of cells in the surrounding neighbourhood of 300 by 300 metres
Terrain (100 m)	Difference in elevation between an individual cell and the mean elevation of cells in the surrounding neighbourhood of 100 by 100 metres
Minimum temp. (July)	Minimum temperature for the coldest month of the year (July) (°C)
Maximum temp. (January)	Maximum temperature for the hottest month of the year (January) (°C)
Solar radiation (July)	Solar Radiation received in the coldest month (July) corrected for terrain and rainfall (Megajoules.metres^{-2}.Day^{-1})
Solar radiation (January)	Solar Radiation received in the hottest month (January) corrected for terrain and rainfall (Megajoules.metres^{-2}.Day^{-1})

Environmental relationships

A range of spatial data layers was used to explore relationships between vegetation composition and the environment as a basis for spatial modelling (Table 2). These data were derived and/or manipulated in a digital format using a Geographic Information System (GIS). Parent geology was obtained from published geology and soil landscape maps (Walker 1960, Chapman & Murphy 1989, Bannerman & Hazelton 1990, Hazelton et al. 1990) and used to derive variables representing gradients in soil characteristics. The location and size of drainage channels (stream order) was estimated by computing flow direction and accumulation from a 5 m grid digital elevation model. Terrain variables ('ruggedness' and 'terrain') were derived from a 25 m grid digital elevation model (Table 2). Climatic variables (rainfall, temperature and solar radiation) were derived from the digital elevation model using ESOCLIM (Hutchinson 1989).

Correlations between floristic composition and environmental variables were explored using hybrid multi-dimensional scaling and principal axis correlation (Belbin 1991). Ordination was performed on a dissimilarity matrix calculated using the symmetric form of the Kulczynski coefficient. Solutions were calculated in 5 and 6 dimensions from 10 random starting configurations and a maximum of 50 iterations. The procedure was terminated if successive iterations produced an improvement in stress of less than 0.005. The choice of solution dimension was designed to minimise stress in the resulting solution and maximise the chances of revealing complex, fine scale correlations in the data, while maintaining computing time at an acceptable level. Ratio regression was applied below ratio/ordinal cut values of 0.9, 0.2 and 0. By reducing the ratio/ordinal cut it was hoped that the solution stress could be further reduced (a non-metric solution was not expected to deteriorate rank correlation in the fitted vectors). The importance of the two ordinal variables (geology and its derivative soil landscapes) could be assumed *a priori* (Benson 1992), thus no attempt was made to correlate them. Principal axis correlation was performed using environmental data derived from the digital data layers in preference to using field data. Variables were ranked in order of correlation and used preferentially in subsequent modelling of community distributions.

Spatial modelling of communities

Spatial interpolation of ecological communities was carried out using a hybrid decision tree/expert system technique developed by Keith and Bedward (1999). This technique utilises purpose-built software (ALBERO) to develop decision rules that quantify the environmental envelope(s) occupied by each community. At each node in the decision tree ALBERO provides a list of variables which could be used to discriminate communities. The variables are selected on the basis of Chi-squared statistics. The level of significance for the test ($p < 0.05$ in this case) and the variable upon which the split is performed are chosen by the user. This technique was used in modelling 79 floristic assemblages in the South East Forests Region of NSW (see Keith & Bedward 1999 for further details).

Decision tree models have the disadvantage of sample numbers diminishing with each successive split in the tree. As a result, split thresholds may be influenced by the position in the tree at which the split is made. Furthermore, diminishing sample numbers can render modelling impossible in areas with inadequate sampling. Several strategies were used to minimise the effects of this limitation. Variables highly correlated with floristic patterns were used preferentially in building the decision tree. Other variables were used sparingly, and only where there was an ecologically intuitive reason for doing so (i.e. splits were not determined on statistical significance alone). Variables describing small-scale gradients were fitted before variables describing gradients across the whole study area. This allowed the exploration of complex patterns using the maximum number of samples. Once this had been achieved the decision tree could be rebuilt commencing with large-scale variables, a conceptually easier task, and where appropriate, the splitting of small-scale variables further along the tree could then be forced to comply with decisions derived using larger sample sizes. Often when a split was made using a large-scale variable, further splits on the same variable were pursued in consecutive nodes. In general, variables yielding splits that isolated small numbers of communities were pursued in preference to variables that split communities evenly. Terminal nodes were assigned to the community represented by the most samples.

A purpose-built mapping program (ALBERO Mapper) was used to compile a 25 m grid coverage from the decision rules and GIS data layers. The development of the coverage was iterative. For each rule set the modelled distribution of each community was assessed through comparisons with the distribution of the sample sites and descriptions of distributions contained in field notes and published reports. Where discrepancies were apparent the decision rules were de-constructed and reapplied as sub-rules to identify the section of the tree responsible. The decision rules were changed if inconsistencies in the construction of the decision tree were identified (e.g. in the way a community was modelled in different branches of the tree). Due to the highly fragmented nature of much of the survey area, parts of the environmental domain could not be sampled. Decision rules were modified to extend the range of some communities based on the interpretation of historical records (Benson 1992, Benson & Howell 1990). The final coverage was smoothed using a majority filter operating over a radius of 50 m.

Accuracy assessment

The accuracy of the community distribution model was assessed using a sample of 80 sites withheld from the modelling process to form a set of independent observations with which the accuracy of model predictions could be tested. Approximately 10% of sites representing each vegetation class were selected randomly for accuracy assessment, with the exception of communities 5, 8 and 34 for which too few samples were available. Accuracy was conceived as a function of the spatial proximity between independent sites of known classification and predicted occurrence of the same class. Therefore, the degree to which model predictions conformed to independent observations was calculated within concentric, circular neighbourhoods of radii increasing from zero to 1000 m in 100 m intervals. Two measures of accuracy were calculated for each neighbourhood size: (i) the percentage of sites for which the site class was predicted to occur within the neighbourhood; and (ii) the proportion of the neighbourhood for which the site class was predicted to occur. The first measure estimates the likelihood of finding an example of the predicted vegetation type within an increasing neighbourhood size around the point for which the prediction is made. The second measure estimates how common the predicted vegetation type is within the site neighbourhood. This measure is subject to the limitation that a uniform distribution of a vegetation class can not be implied beyond a neighbourhood range of approximately 100 m from a site, therefore there is no expectation that the community may occur beyond this range. Therefore, the second measure was calculated for a 100 m neighbourhood radius only.

The extent to which field survey sites sampled environmental gradients was assessed by estimating environmental redundancy (Faith 1996) for cells in a 25 m grid covering the study area. A p-median calculation was used as an estimate of the environmental diversity represented by sites in multi-dimensional space. Using the existing field sites as a basis for comparison, the change in p-median following the addition of new sites was calculated as a measure of the redundancy of each potential new site. The calculation was performed for each of 10 000 new sites located randomly within the study area and the results were subjected to a spatial interpolation. Values in the resulting grid varied within a range determined by the most and least redundant sites within the random sample. Assuming that 10 000 sites (approximately 20 times as many as actually sampled) were sufficient to sample environmental diversity within the study area, areas of low redundancy represent gaps in the sample coverage.

Two analyses were completed to assess the adequacy of the sample coverage. In the first analysis environmental diversity was represented by the 3 variables used to stratify field sampling (geology, rainfall and temperature) in order to gauge how well the field survey strategy was executed. The second analysis tested sampling adequacy across environmental gradients that were identified by gradient analysis as highly correlated with floristic variation (Table 3). Environmental diversity was represented by geology, rainfall, temperature, elevation, solar radiation index for July, maximum temperature (January), minimum temperature (July), ruggedness (700 m domain) and slope.

Mapping of woody vegetation

Aerial photograph interpretation (API) was carried out by an independent consultant (Roberts 1999) to determine the extent of remnant woody vegetation. Colour aerial photographs captured at an approximate scale of 1:16 000 were obtained from QUASCO NSW and interpreted stereoscopically by a single observer in conjunction with extensive ground traverses (flown 25/11/97–11/3/98; film nos 3171c, 3172c, 3173c, 3174c, 3175, 3193c, 3194c, 3199c, 3200c; runs 19, 20–23w, 24–27w, 24–27e, 28–30, 31w, 31e, 32–45, 46w, 47–55). Areas with no tree or shrub cover were excluded from analysis. The remaining area was divided into 6 classes on the basis of projected *Eucalyptus* crown cover and land use: A (crown cover ≥10%); B (crown cover < 10%, low intensity agricultural (grazing) activity or no activity); C (no *Eucalyptus* crown cover, low intensity agricultural (grazing) activity or no activity); Tx (crown cover < 10%, high intensity agricultural activity such as cultivation, intensive stocking); TXR (crown cover < 10%, rural residential development); and TXU (crown cover < 10%, urban development). The minimum polygon size delineated for polygon classes A and B was 0.5 and 5 ha, respectively. The delineation of the remaining classes was subjective by nature therefore no minimum polygon size was specified.

The range of API crown cover classes sampled by the survey sites was determined in order to identify the subset of API crown cover classes most closely approximating the extent of remnant native vegetation (i.e. those dominated by a diversity of native species). Associations between structural features mapped by API and vegetation communities were identified using survey quadrat data, general field observations and features such as the shape and position of the structural unit in the landscape. The spatial distribution of each crown cover class was also compared with vegetation maps for the Sydney (Benson & Howell (1994a), Penrith (Benson 1992) and Wollongong (Benson & Howell 1994b) 1:100 000 map sheets.

Map compilation

A map of extant native vegetation was compiled using a geographic information system (GIS) to cut the community distribution model based on information acquired by aerial photograph interpretation. The distribution model was then further refined using a map of canopy species composition, which was derived by API using patterns in texture, structure and colour to interpolate field observations. Polygons for which the canopy composition (determined by API modelling) was not consistent with the community classification (determined by spatial modelling) were assessed to determine if a change in community classification was warranted. Inconsistency was defined as a canopy composition type that was not recorded in field survey samples representing the mapped community type, and indicated that either the spatial model or the API model (or both) was in error. The modelled community classification was retained if it was verified by the presence of field survey sites of the same classification or other field observations in the area. The community classification was changed where it could be demonstrated that the presence of an alternative community was likely, provided that survey sites for the alternative community contained the species listed in the API canopy composition class. API was used extensively to map the distribution of distinctive communities not dominated by *Eucalyptus* species (e.g. *Casuarina* spp., *Melaleuca* spp., mangroves, saltmarsh, freshwater wetlands, swamps, sedgeland).

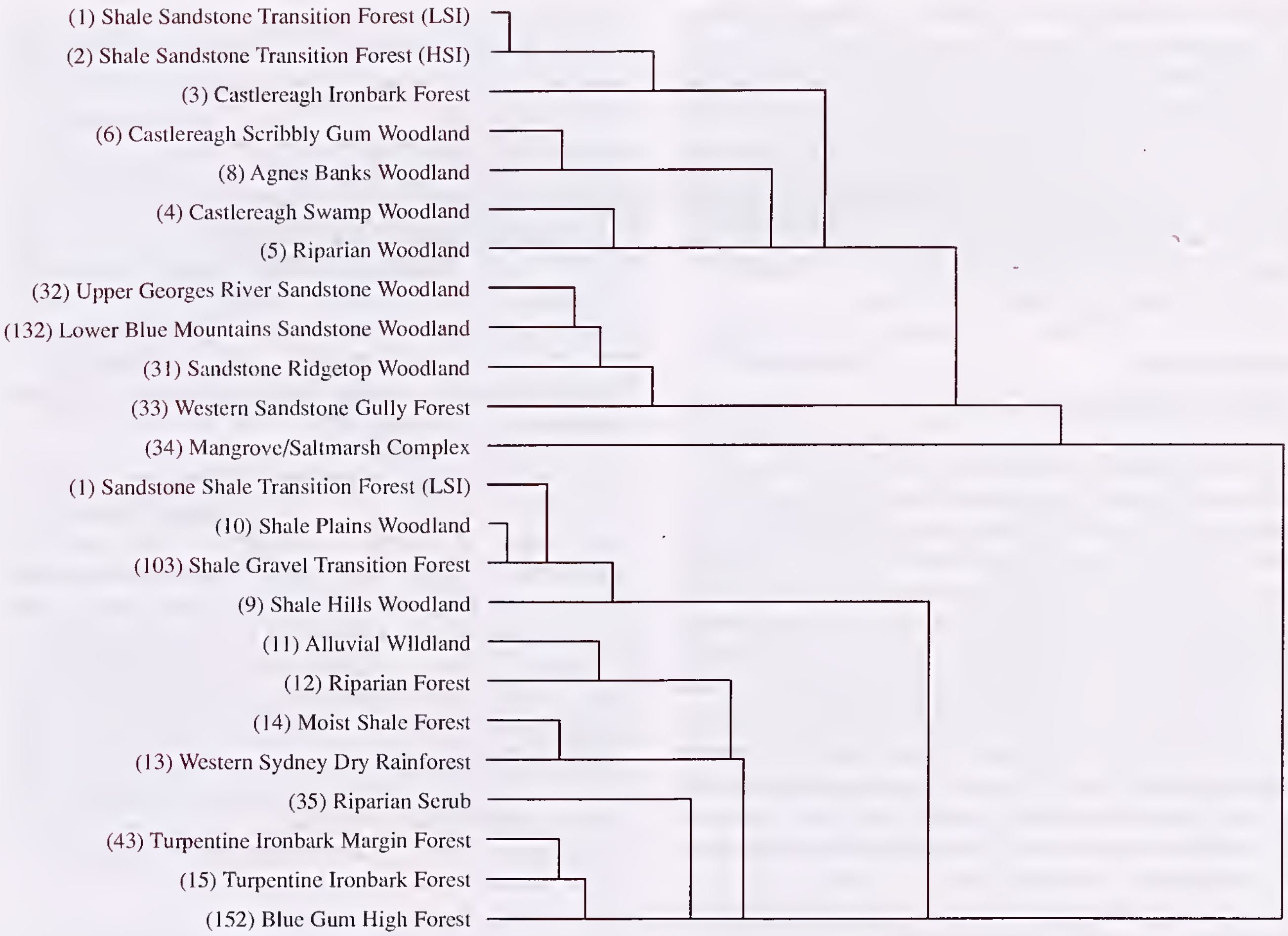
(1) Shale Sandstone Transition Forest (LSI)
(2) Shale Sandstone Transition Forest (HSI)
(3) Castlereagh Ironbark Forest
(6) Castlereagh Scribbly Gum Woodland
(8) Agnes Banks Woodland
(4) Castlereagh Swamp Woodland
(5) Riparian Woodland
(32) Upper Georges River Sandstone Woodland
(132) Lower Blue Mountains Sandstone Woodland
(31) Sandstone Ridgetop Woodland
(33) Western Sandstone Gully Forest
(34) Mangrove/Saltmarsh Complex
(1) Sandstone Shale Transition Forest (LSI)
(10) Shale Plains Woodland
(103) Shale Gravel Transition Forest
(9) Shale Hills Woodland
(11) Alluvial Wlldland
(12) Riparian Forest
(14) Moist Shale Forest
(13) Western Sydney Dry Rainforest
(35) Riparian Scrub
(43) Turpentine Ironbark Margin Forest
(15) Turpentine Ironbark Forest
(152) Blue Gum High Forest

Fig. 3. Dendrogram showing the hierarchical relationship between vegetation communities.

Following the completion of changes suggested by structural features mapped by API, the map was examined to identify anomalies in the distribution of vegetation communities with respect to the location of field survey sites or other field observations. At this stage the map was assessed by independent botanists for consideration of further changes based on expert opinion.

The degree to which observer bias (Roberts 1999) may influence estimates of remaining vegetation cover was assessed by using an independent interpreter to repeat the procedure for a small section (8836 ha) of the study area. The range of observer bias was calculated as the difference between the areas represented by the union and intersection of the two observers' outputs. Based on an assumption that the range magnitude is proportional to the perimeter of remnants, the average area of disagreement was calculated by dividing the range by the length of the perimeter of remnant vegetation in the section used for comparison. This figure was used to calculate the potential range for estimates of the area extant for each vegetation community by multiplying by the length of perimeter over which the community boundary coincided with a remnant boundary. Range estimates were thus based on the assumption that the observer differences measured in a subset of the study area would apply to all communities throughout the study area.

Results

Classification

Cluster analysis of 652 sample sites resolved a hierarchical classification of 24 communities (Figure 3) occurring on or adjoining the Cumberland Plain, including seven communities occurring on soils derived from Wianamatta Shale, four on Tertiary alluvium, three on quaternary alluvium, five on sandstone, one each on estuarine sediments and aeolian sand deposits and three restricted to areas transitional between shale and sandstone soils. The principal dichotomy in the hierarchy was between sites located on sandy soils from those located on clay-loam soils derived from shale or alluvium (Figure 3). One community (Map Unit 1; Sandstone shale transition forest (Low sandstone influence)) was represented in the dendrogram by a cluster on each side of the shale/sandstone dichotomy, reflecting the transitional nature of soils at those sample sites. Repeated clustering using different association measures (Kulczynski v. Bray-Curtis) and various subsets of the data demonstrated that the location of the second cluster was unstable: it would often join with the first cluster in the top half of the dendrogram. Similar behaviour was observed for the cluster representing Map Unit 103 (Shale Gravel Transition Forest). This cluster joined alternately with Map Units 3 (Castlereagh Ironbark Forest) and 10 (Shale Plains Woodland), which was again a reflection of the transitional nature of the soils at the sample sites. Freshwater wetlands were not sampled in this survey, but are recognised as a unique floristic assemblage and mapped using aerial photograph interpretation. Full descriptions of the structure, physical habitat and lists of characteristic species are present for each community in Appendix 1. Diagnostic species are listed in alphabetical order within broadly defined growth forms.

Species richness

A total of 1195 species (975 native and 220 exotic) were recorded in 652 survey sites. With sites representing sandstone communities excluded, some 831 native species were recorded for the Cumberland Plain. This figure is close to the estimate of a flora of 800 species made by James et al. (1999). Forty-six percent of native species were recorded five times or less, while 22% were recorded in one sample only. Species richness varied considerably between communities from an average of 6.3 (±7.5) taxa per plot recorded for Map Unit 34 (Mangrove/Saltmarsh Complex) to 53.1 (±8.2) taxa per plot recorded on average in Sandstone Ridgetop Woodland (Appendix 1). Species richness tended to increase along a continuum from the central Cumberland Plain to the margins. Communities on shale derived soils generally recorded fewer species per sample than shale/sandstone transitional areas, which in turn had fewer species than communities on sandstone. Species richness in communities on alluvial soils on the Cumberland Plain tended to be slightly lower than in the surrounding shale communities. Communities on Tertiary alluvium were intermediate in species richness, with more species recorded on sandy soils than clay/loam soils.

The highest number of species recorded in any assemblage was 379, in Map Unit 2 (Shale Sandstone Transition Forest (High sandstone influence)). This assemblage also contained a large number of species (15) not recorded in other communities. All communities contained species not recorded in other communities (Appendix 1). Communities with very low numbers of unique species were Shale Gravel Transition Forest (Map Unit 103) (1 species), Agnes Banks Woodland (Map Unit 8) (1 species) and Castlereagh Ironbark Forest (Map Unit 3) (4 species). The number of taxa recorded in each community is likely to be related to sampling intensity. For example, Agnes Banks Woodland (Map Unit 8) was sampled at only 2 sites, and only 52 species were recorded. The actual number of taxa represented in this community is likely to be considerably higher (see Benson 1981, 1992). There was a weak inverse correlation between the number of native species recorded at a survey site and the ratio of perimeter to area for the remnant in which the site was located (R = -0.35, $p < 0.001$). The number of species recorded was positively correlated with remnant size (R = 0.42, $p < 0.001$), however some sites located in small remnants contained as many species as those in larger remnants.

A total of 220 exotic species was recorded in the survey however this number is likely to be an underestimate of the introduced flora because highly disturbed and weed infested areas were avoided when selecting sites for survey. Exotic species were most common at sites with alluvial soil and least common at sites with soil derived from sandstone or Tertiary alluvium. Exotic species were also common on soils derived from Wianamatta Shale. Nine species were recorded in more than 20% of all sample sites. These species were: *Senecio madagascarensis* (52%), *Cirsium vulgare* (34%), *Hypochaeris radicata* (32%), *Olea europea* subsp. *africana* (27%), *Setaria gracilis* (26%), *Plantago lanceolata* (26%), *Sida rhombifolia* (25%), *Myrsiphyllum asparagoides* (22%), and *Sonchus oleraceus* (22%).

One hundred and nine exotic species showed an association with particular communities, while a further 69 occurred at high frequency across a wide range of communities (Appendix 1). The number of weeds recorded in a survey site was correlated with the perimeter to area ratio for the remnant in which it was located ($R = 0.47$, $p < 0.001$). There was also a weak inverse correlation between the number of exotic species recorded and the distance at which the survey site was located from the edge of the remnant (R = -0.29, $p < 0.001$). The relatively low R value reflected the fact that while sites located at greater distances from the remnant edge rarely contained many exotic species, those close to the edge were equally likely to contain large or small numbers.

Field identification of communities

Appendix 1 contains a list of diagnostic species for each community and an outline of the procedure for community identification. Diagnostic species are sorted into two fidelity classes: (i) positive (the species occurs more frequently in the target group than in all survey sites combined); and (ii) constant (the species occurs frequently in the target group and other groups, and is therefore characteristic rather than diagnostic of the target group. Fidelity classes are a measure of the relative likelihood that a species will be recorded in a 0.04 ha sample plot randomly located in the vegetation community. Therefore, obtaining such a sample is a pre-requisite for the use of diagnostic species. The number of positive diagnostic species present in a sample can be used to identify the community type by ruling out all but a few feasible alternatives. For each community type a minimum expected number of positive diagnostic species has been calculated. The presence of the minimum number of species in a sample is strong evidence that the sample belongs to the vegetation community. This assumes that all vascular plant species occurring in the sample area were correctly identified and the total number of species recorded in the sample exceeds a specified minimum (species-poor sites can not be tested).

The presence of fewer than the minimum expected number of diagnostic species may be considered evidence that the sample does not belong to the community type under consideration. In such cases there is a 5% chance of error (i.e. if the sample does, in fact, belong to that community type then there is a 5% chance that it will nevertheless contain fewer than the minimum expected number of diagnostic species).

In addition to the 'true' community, a sample may contain the minimum expected number of diagnostic species for 1–5 other communities (average 1.25). In most cases, sites contain the minimum number of species for communities closely related to the 'true' community. For example, Shale Plains Woodland (Map Unit 10) grades into Map Units 1, 2, 9, 11 and 103. Sites located in Shale Plains Woodland frequently contain the minimum number of positive diagnostic species for one or more of these communities. In such cases the number of species by which the minimum was exceeded may be used to assess the closeness of the match to each of the possible candidates.

Correlation with environmental variables

Reducing the ratio/ordinal cut values from 0.9 to 0.2 resulted in a marked improvement in stress for ordination solutions in both five and six dimensions. No further improvement in stress resulted when the cut was reduced from 0.2 to 0.0; thus both solutions were equally acceptable. The 6 dimensional solution calculated with a ratio/ordinal cut of 0.0 was used for correlation with environmental variables.

Variables likely to influence floristic composition at a local scale were most strongly correlated with floristic patterns among sites on the Cumberland Plain (Table 3). These include ruggedness (all neighbourhood sizes), slope and solar radiation, which are also expected to correlate strongly with each other given the influence of topography on exposure to solar radiation. Variables such as maximum temperature (January) and annual rainfall that represent patterns in floristic composition at a regional scale were also strongly correlated. Elevation was strongly correlated in the ordination space, but topographic position and terrain (all neighbourhood sizes), which describe the relative position on localised elevation gradients, were less strongly correlated. This suggests that variation in elevation correlates most strongly with floristic patterns at a regional scale. Despite the strong correlation with solar radiation, aspect was not correlated in the ordination space. Large discrepancies were observed between aspect measured in the field and aspect derived from the digital elevation model, which suggests that the elevation model may be insensitive to variation in aspect at a fine scale.

Distribution modelling

A total of 232 rules applying to 27 variables were constructed to estimate the pre-European spatial extent of ecological communities. The final rule set represents a complete revision of an earlier version (NPWS 2000) and incorporated 105 additional field survey sites. Refinements to the rule set have been carried out through approximately 17 iterations. Each rule defined a subset of the spatial extent of a community by specifying the environmental conditions within which the community was predicted to occur. For example, the following conditions constitute a rule defining a subset of the spatial extent of Western Sydney Dry Rainforest:

Geology = Wianamatta Shale AND Distance to the shale/sandstone Boundary > 1.7 km AND Elevation > 163 m AND Distance to a stream < 60 m AND Slope > 18°.

Table 3. Rank correlation of variables in an ordination space of six dimensions

Variable	Correlation	Scale of influence
Ruggedness (700 m)	0.708	Local
Ruggedness (500 m)	0.701	Local
Ruggedness (900 m)	0.699	Local
Ruggedness (300 m)	0.665	Local
Ruggedness (100 m)	0.651	Local
Slope	0.635	Local
Elevation	0.619	Regional (Local?)
Solar radiation (January)	0.580	Local
Maximum temperature (January)	0.527	Regional
Annual rainfall	0.518	Regional
Distance to sandstone	0.516	Local (Regional?)
Wetness	0.469	Local
Minimum temperature (July)	0.421	Regional
Distance to stream	0.401	Local
Topographic position	0.380	Local
Terrain (900 m)	0.355	Local
Terrain (700 m)	0.351	Local
Terrain (500 m)	0.342	Local
Solar radiation (July)	0.329	Local
Terrain (300 m)	0.306	Local
Distance to coast	0.260	Regional
Terrain (100 m)	0.150	Local

Rules contained between 2 and 14 conditions. The number of rules required to define the full extent of each community varied from 1 (Mangrove/Saltmarsh Complex and Agnes Banks Woodland) to 32 (Cumberland Plain Woodland). The number of rules compiled per community was strongly correlated with the number of field samples representative of that community ($R = 0.8$, $p < 0.001$). This relationship is partly explained by the fact that some communities were strongly associated with geological substrates of limited distribution (and hence were allocated a small number of samples). The distributions of some of these communities were easy to model with a small number of rules. However, in other cases small numbers of samples precluded the compilation of multiple rules because insufficient replicates were available for reliable choices to be made at multiple nodes in the tree. This reduced the extent to which interactions between variables could be explored in explaining community distribution.

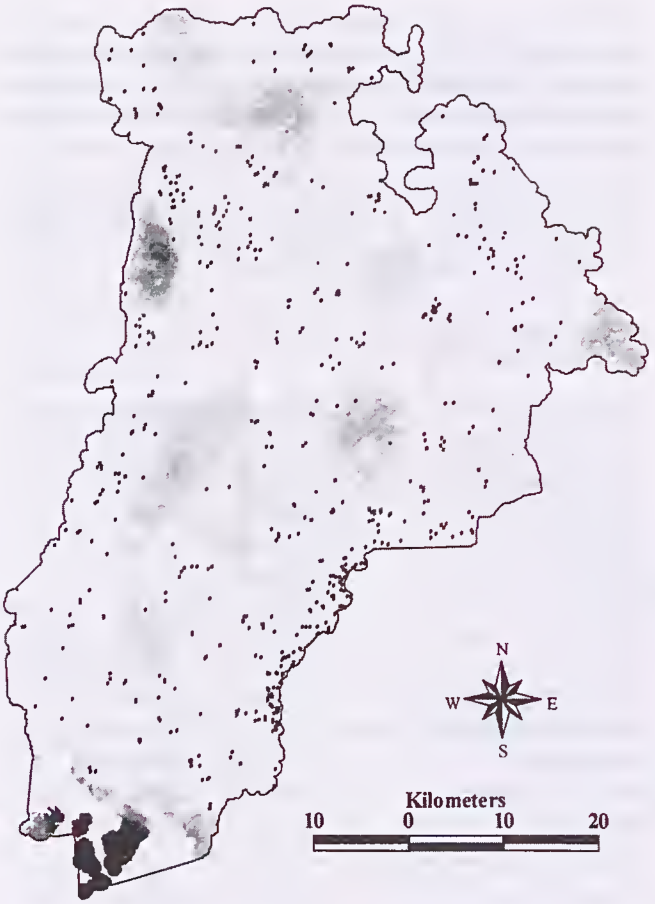

Fig. 4. The location of field sample sites (filled circles) and the intensity with which environmental strata were sampled. Darker shading indicates lower sampling intensity.

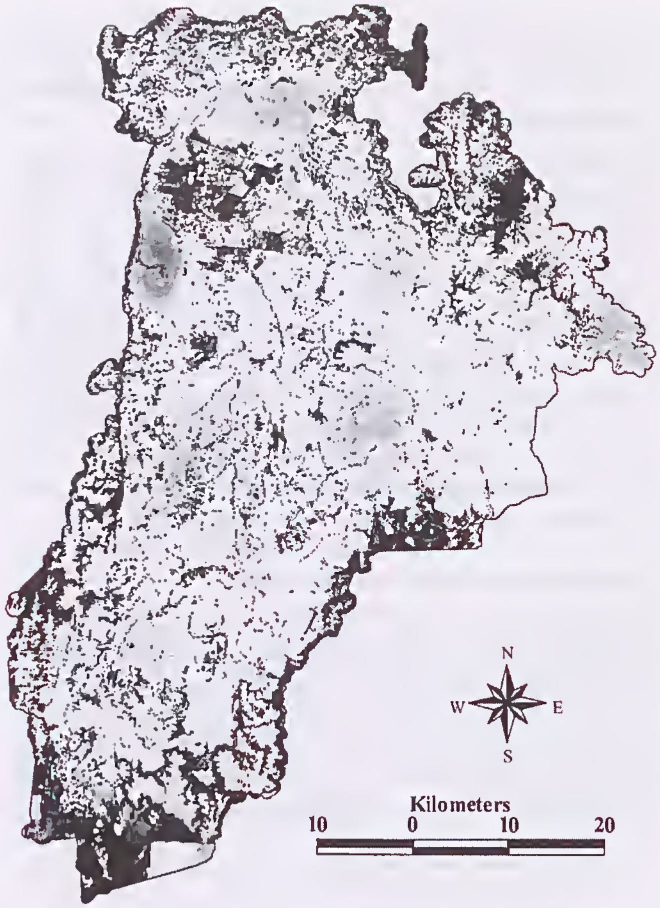

Fig. 5. The location of remnant native vegetation (shaded black) in relation to sampling intensity. Background shading indicates sampling intensity as shown in Figure 4.

The most frequently used variables in the rule set were geology, elevation and distance to stream (Table 4). The primary node of the tree split samples into five geological classes: Wianamatta Shale, Holocene alluvium, Tertiary alluvium, Estuarine sediments and Aeolian Deposits. Higher order splits within shale sites were predominantly based on rainfall and elevation, with slope, aspect and terrain used frequently in lower order splits. Distance to streams, distance to sandstone and distance to Tertiary alluvium were used extensively to model community distribution in areas of transition between substrates. Communities on Tertiary alluvium were split on the basis elevation, slope and ruggedness, with distance to streams and shale soils also used extensively. Distance to streams was used to model the distribution of riparian communities beyond the mapped distribution of alluvial soils. Riparian Woodland was represented by too few samples for modelling and none is represented in the distribution map. However, Riparian Woodland may be assumed to be present along at least the higher order streams in areas mapped as Map Unit 11 (Alluvial Woodland). The extent of Freshwater Wetlands (Map Unit 36) was represented by the mapped distribution of the Bakers Lagoon soil landscape (Bannerman & Hazelton 1990) consistent with the interpretation of Benson (1992). Additional wetlands were added using API.

Model evaluation

Model accuracy statistics are the percentage of independent survey sites for which the model accurately predicted the occurrence of a vegetation community within a given radius of the site. Accuracy ranged from 50 % at the point scale (zero radius) to 98% at a radius of 700 m. At a radius of 100 m (the estimated error in determining the site's true position) the model was accurate in 74% of sites, while an average of 44% of the neighbourhood was predicted to contain the correct vegetation community. Ninety-five percent accuracy was achieved within a 500 m radius. Therefore, a minimum polygon size of 79 ha is required to ensure a 95% chance that a selected area will contain the predicted community type. By comparison, some 2890 of the mapped polygons (97% of all polygons, 52% of extant vegetation) are less than 79 ha in area. Furthermore, 1530 of polygons (51% of all polygons, 6% of extant vegetation) are less than 3.14 ha in area, at which scale 74% accuracy is expected.

Limited conclusions can be drawn about the accuracy with which individual communities were modelled due to the small number of sites that could be spared for accuracy assessment. Based on a limited sample, most communities were modelled with acceptable accuracy at a scale of 500 m. Communities that appear to have been mapped less accurately include 3, 6 and 103. For most communities the correct community type was the most frequent community type predicted to occur within the neighbourhood.

Table 4. The number of times variables were used in a total set of 94 decision rules.

Variable	Number of rules
Geology	29
Elevation	25
Distance to stream (any order)	25
Distance to shale	14
Annual rainfall	13
Northing	12
Slope	11
Distance to sandstone (2)	11
Easting	11
Ruggedness (700 m)	9
Distance to Tertiary alluvium	9
Aspect	9
Ruggedness (900 m)	7
Terrain (900 m)	6
Topographic position	6
Soil landscape	4
Distance to sandstone (1)	4
Terrain (700 m)	4
Distance to stream (order 5,6 or 7)	2
Solar radiation (January)	2
Ruggedness (500 m)	2
Terrain (300 m)	2
Maximum temperature (July)	1
Ruggedness (300 m)	1
Distance to coast	1
Distance to stream (order 1)	1
Terrain (100 m)	1

The density of field survey sites was approximately 0.2 sites/km^2 across the study area as a whole and 0.7 sites/km^2 of extant vegetation. Samples were distributed relatively evenly among soil substrates and across environmental gradients, although some gaps in the sample coverage were evident (Figure 4). Sampling of the major alluvial deposits of the Hawkesbury–Nepean floodplains was inevitably inadequate due to the scarcity of remnant native vegetation on this substrate (Figure 5). Other gaps were associated with a lower intensity of sampling at the northern and southern extremities of the study area, coincident with extremes of temperature and annual rainfall. These include a combination of relatively high rainfall and summer temperature maxima at higher elevations to the east of Kurrajong compared with lower summer temperatures combined with higher rainfall in the vicinity of Bargo. Areas in the eastern extremity of the study area experiencing a combination of high rainfall, cooler summer maxima and warmer winter maxima were also poorly sampled, but are largely devoid of native vegetation. Some central sections of the study area were also identified as areas warranting further sampling (Figure 4). While sampling in these areas was obviously deficient it is not clear what environmental strata are under-represented.

Table 5. Distribution of study area and survey sites among Aerial Photograph Interpretation classes.

Polygon Class	Area(ha) (% study area)		No. Sites (%)	
A	47887	(14.3)	486	(77.1)
B	26867	(8.0)	65	(10.3)
C	4998	(1.5)	15	(2.4)
TX	24042	(7.2)	39	(6.2)
TXR	10519	(3.1)	10	(1.6)
TXU	13079	(3.9)	11	(1.7)
X	206608	(61.9)	4	(0.6)

Mapping of woody vegetation

Aerial photograph interpretation (API) was carried out over an area of approximately 334 000 ha. Most of this area is devoid of tree cover (Table 5) and only 47 887 ha (14.3%) supports *Eucalyptus* species with cover greater than 10% (class A polygons). Field survey sites were most frequently located in polygons of class A (Table 5), although sites were located in all classes, including 60 sites (10%) in polygons delineating scattered tree cover (TX, TXU, TXR) and 4 sites (0.6%) in polygons devoid of tree cover. This suggests that while most remnant woody vegetation is represented by classes A and B, these classes do not represent the full extent of native vegetation. This conclusion is supported by a comparison with other vegetation maps within the study area. For example, remnant vegetation mapped by Benson (1992) is concentrated in (and evenly distributed between) polygons of classes A and B, but 11% of the area is located in polygons delineating scattered tree cover (TX, TXU, TXR) or polygons devoid of tree cover.

The current extent of woody native vegetation was best represented by polygons of classes A and B combined with a relatively small area mapped with non-*Eucalyptus* canopy cover (class C). The estimated extent of each community prior to clearing and the area extant at the end of 1997 is given in Table 6. Communities occurring on land with a high capacity to support agricultural and urban development have been most extensively cleared. Turpentine–Ironbark Forest (1.4 ± 0.3% extant) and Blue Gum High Forest (4.5 ±0.8% extant) were the most heavily cleared of all communities. These forests occur in the higher rainfall zone on the east of the study area and were harvested for timber and cleared for market gardens and orchards. Most of the original distribution of these communities has been subjected to urban development, with the exception of parts of the broad Castle Hill–Arcadia ridgeline. On the margins of the plateaus where the shale soils become shallow, clearing has been slightly less severe, with 7.3 ±1.4% of Turpentine–Ironbark Margin Forest remaining.

On the Cumberland Plain, only 7.7 ±1.1% of Shale Plains Woodland is estimated to remain. This proportion increases with increasing sandstone influence in the soil to 26.8 ±2.8%

Table 7. The percentage of field samples in each overstorey canopy type as determined by aerial photograph interpretation.

Typical Soil type:	**Sandstone**				**Sandstone/shale**			**Shale**					**Recent alluvium**			**Tertiary alluvium**				**Sand**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**
Overstorey species (determined by API)																				
Tristaniopsis laurina, *Casuarina* spp.	25	2																		
Eucalyptus pilularis	25	49	11	7	7															
E. deanii, *E. saligna*		8			20		3			28										
E. saligna, *E. pilularis*, *E. paniculata*, *E. globoidea*		2								22										
E. piperita	25	4								17										
E. piperita, *E. deanii*		4								6										
E. gummifera, *E. oblonga*, *E. sieberi*, *E. piperita*		16	42	19		5														
E. sclerophylla/*E. racemosa*/*E. haemastoma*			11																	
E. piperita, *E. punctata*					7															
E. pilularis, *E. punctata*	25	10	5	12	13	9	3													
E. punctata		4	26	49	20	50	38	3		22	11		13			5				
E. sclerophylla			5	7		4										5	5	17	40	
E. sclerophylla, *Angophora bakeri*, *Banksia serrata*																	5			50
E. moluccana, *E. tereticornis*				5	7	7	32	64	78		56	63	34	100	14	40	5	33		
E. maculata				2		13	9	4	2		22	25								
E. beyeriana/*E. crebra*						4	3	18	15			13	3			15				
Syncarpia glomulifera, *E. paniculata*					7					6							9			
E. fibrosa						5	12									10	5			
E. fibrosa, *E. crebra*						4		10								25	18	17		
A. subvelotina, *E. amplifolia*,*E. tereticornis*								3	5				47							
E. benthamii															14					
E. botryoides															29					
E. baueriana, *E. elata*													3		43					
E. elata											11									
E. amplifolia, *E. parramattensis*																		33		
E. resinifera					20															
E. fibrosa, *Melaleuca* spp.																	50		4	
E. sclerophylla, *E. fibrosa*																	5		12	
E. parramattensis																			12	
E. parramattensis, *E. sclerophylla*																			32	50

Table 6. Estimates of contemporary (Nov. 1998) and pre–European extent of native vegetation communities on the Cumberland Plain. No estimates were made for Riparian Woodland (Map Unit 5).

Assemblage	Map Unit	Pre–European Extent (ha)	1997 Extent (ha) (± range)	1997 Extent (%) (± range)
Shale/Sandstone Transition Forest (Low Sandstone Influence)	1	12 834	1 243 (±173)	9.7 (±1.3)
Shale/Sandstone Transition Forest (High Sandstone Influence)	2	32 521	8 717 (±912)	26.8 (±2.8)
Total Shale/Sandstone Transition Forest		**45 355**	**9 960 (±1085)**	**22.0 (±2.4)**
Castlereagh Ironbark Forest	3	12 211	1 012 (±99)	8.3 (±0.8)
Castlereagh Swamp Woodland	4	1 006	616 (±27)	61.2 (±2.7)
Castlereagh Scribbly Gum Woodland	6	5 852	3 083 (±171)	52.7 (±2.9)
Shale/Gravel Transition Forest	103	5 427	1 721 (±170)	31.7 (±3.1)
Agnes Banks Woodland	8	627	98 (±8)	15.6 (±1.3)
Riparian Woodland	5	–	–	–
Alluvial Woodland	11	36 129	4 698 (±903)	13.0 (±2.5)
Riparian Forest	12	2 989	717 (±137)	24.0 (±4.6)
Total Sydney Coastal River Flat Forest		**39 118**	**5 415 (±1040)**	**13.8 (±2.7)**
Shale Hills Woodland	9	38 274	4 309 (±596)	11.3 (±1.5)
Shale Plains Woodland	10	87 175	6 745 (±968)	7.7 (±1.1)
Total Cumberland Plain Woodland		**125 449**	**11 054 (±1564)**	**8.8 (±1.2)**
Dry Rainforest	13	1 282	338 (±35)	26.4 (±2.7)
Moist Shale Woodland	14	2 034	604 (±65)	29.7 (±3.2)
Turpentine–Ironbark Forest	15	17 354	236 (±49)	1.4 (±0.3)
Turpentine–Ironbark Margin Forest	43	12 985	947 (±178)	7.3 (±1.4)
Total Sydney Turpentine Ironbark Forest		**30 339**	**1 183 (±227)**	**3.9 (±0.7)**
Blue Gum High Forest	152	3 720	168 (±31)	4.5 (±0.8)
Freshwater Wetlands	36	1 552	664 (±82)	42.8 (±5.3)
TOTAL		**273 972**	**35 916 (4604)**	**13.1 (±1.7)**

for shale/sandstone transition forest (high sandstone influence). The proportion of pre-European vegetation remaining also increases with increasing topographic variability to 11.3 ±1.5% for Shale Hills Woodland and 29.7 ±3.2% for Moist Shale Woodland. Although the fertile alluvial soils of the floodplains have been highly sought for agriculture, remnants of Alluvial Woodland (13.0 ±2.5%) and Riparian Forest (24.0 ±4.6%) survive immediately adjacent to waterways. The most extensive remnants on the Plain occur on the tertiary sediments of the Castlereagh area where an estimated 52.7 ±2.9% of Castlereagh Scribbly Gum Woodland and 61.2 ±2.7% of Castlereagh Swamp Woodland remain. However, sand and gravel extraction threaten these and other communities in the area such as Agnes Banks Woodland (15.6 ±1.3%) and Castlereagh Ironbark Forest (8.3 ±0.8%). Although a relatively high proportion of some communities may remain, the area occupied by each community on the Cumberland Plain is extremely small.

Map compilation

Field survey sites were located in a total of 30 API canopy composition classes (Table 7). Sites of identical community type were distributed among an average (± s.d.) of 5.5 (± 2.2) API classes. Considerable overlap in canopy composition was evident between community types, particularly those closely related (Table 7). The most widely represented canopy dominants were *Eucalyptus moluccana* and *E. tereticornis*: sites falling within polygons with this canopy composition class represented 15 different vegetation communities. *Eucalyptus punctata* was also widely represented as a dominant (12 vegetation communities).

Polygons covering an area of 6085 ha (12.7% of the total polygon area) contained conflicting classifications for API canopy composition and vegetation community type. Conflicts were resolved by changing the vegetation community classification to match that of a vegetation type occurring nearby (or predicted to occur nearby) for which the API canopy composition was in concord. No change was made where no alternative classification could be suggested or where field observations or other data were judged more reliable than the API.

The range in area allocated to different polygon classes by two independent observers as a percentage of the area compared (8836 ha) was 9% (*Eucalyptus* canopy > 5%), 12% (*Eucalyptus* canopy < 5%) and 9% (cleared land). The potential area attributable to remnant native vegetation ranged from 5891 to 6717 ha. The perimeter length of remnant vegetation estimated by one of the observers (Roberts 1999) was 424 km; thus the average disagreement was 1.9 ha.km^{-1}. Estimates of the area of extant vegetation were estimated to range between 6% (Castlereagh Swamp Woodland) and 29% (Turpentine–Ironbark Forest) either side of the mean. Range estimates for the percentage of each community extant are given in Table 6.

Table 8. The relationship between ecological communities defined in this survey and communities described in previous studies, or listed on Schedule 1 of the NSW *Threatened Species Conservation Act* (1995)

This Survey	Map unit	NSW Threatened Species Act (Gazettal Date)	The Natural Vegetation of the Penrith & Sydney 1:100000 Map Sheets; Benson (1992), Benson & Howell (1994a)	Urban Bushland Biodiversity Survey, NPWS (1997)
Shale/Sandstone Transition Forest (Low Sandstone Influence)	1	Shale/Sandstone Transition Forest (11/09/98)	–	Western Shale/Sandstone Transition Forest
Shale/Sandstone Transition Forest (High Sandstone Influence)	2	Shale/Sandstone Transition Forest (11/09/98)	–	Western Shale/Sandstone Transition Forest
Castlereagh Ironbark Forest Eastern Shale/Sandstone Transition Forest	3	Cooks River/Castlereagh Ironbark Forest (10/5/02)	Castlereagh Ironbark Forest (9e),	Castlereagh Ironbark Forest, Shale/Gravel Transition Forest (9d)
Castlereagh Swamp Woodland	4	Castlereagh Swamp Woodland (24/12/99)	Swamp Woodland (14c)	Castlereagh Swamp Woodland
Riparian Woodland	–	Sydney Coastal River Flat Forest (12/02/99)	River Flat Forest (9f)	River-flat Forest (Riparian Habitats)
Alluvial Woodland	11	Sydney Coastal River Flat Forest (12/02/99)	River Flat Forest (9f)	River-flat Forest (Cumberland Plain creek systems)
Riparian Forest	12	Sydney Coastal River Flat Forest (12/02/99)	River Flat Forest (9f), Camden White Gum Forest (6d)	River-flat Forest (Hawkesbury-Nepean River and major tributaries)
Castlereagh Scribbly Gum Woodland	6	Not listed	Castlereagh Scribbly Gum Woodland (14a)	Castlereagh Scribbly Gum Woodland
Agnes Banks Woodland	8	Agnes Banks Woodland (17/11/00)	Agnes Banks Woodland (14b)	Agnes Banks Woodland
Mapped, but not described	–	Elderslie *Banksia* Scrub Forest (9/10/98)	–	Elderslie *Banksia* Scrub/Forest
Shale Hills Woodland Grey Box –Ironbark Woodland	9	Cumberland Plain Woodland (13/06/97)	Spotted Gum Forest (9b), Grey Box Woodland (10c),	Spotted Gum Forest, Grey Box Woodland, Grey Box –Ironbark Woodland (10d)
Shale Plains Woodland Grey Box –Ironbark Woodland	10	Cumberland Plain Woodland (13/06/97)	Spotted Gum Forest (9b), Grey Box Woodland (10c),	Spotted Gum Forest, Grey Box Woodland, Grey Box –Ironbark Woodland (10d)
Western Sydney Dry Rainforest	13	Western Sydney Dry Rainforest (12/11/99)	–	Dry Rainforest
Moist Shale Woodland	14	Moist Shale Woodland (19/4/02)	–	–
Turpentine-Ironbark Forest	15	Sydney Turpentine Ironbark Forest (16/10/98)	Turpentine-Ironbark Forest (9o)	Turpentine-Ironbark Forest
Turpentine-Ironbark Margin Forest	43	Sydney Turpentine Ironbark Forest (16/10/98)	Turpentine-Ironbark Forest (9o)	Western Shale/Sandstone Transition Forest
Blue Gum High Forest	152	Blue Gum High Forest (05/09/97)	Blue Gum High Forest (6b)	Blue Gum High Forest
Shale/Gravel Transition Forest	103	Shale/Gravel Transition Forest (19/4/02)	Shale/Gravel Transition Forest (9d)	Shale/Gravel Transition Forest
Freshwater Wetlands	36	Sydney Freshwater Wetlands Complex (22/12/00)	Freshwater Wetlands (28a)	River-flat Forest (Wetlands)

Discussion

Classification

The survey results generally corresponded well with previously derived classifications for the Cumberland Plain (Table 8). Seven communities (Castlereagh Ironbark Forest, Castlereagh Scribbly Gum Woodland, Agnes Banks Woodland, Castlereagh Swamp Woodland, Shale Gravel Transition Forest, Turpentine Ironbark Forest and Blue Gum High Forest) were judged to be equivalent to those of the same name described by Benson (1992) and Benson and Howell (1990) (subsequently recognised by NPWS (1997).

Cluster analysis did not support the subdivision of Cumberland Plain Woodlands into the three communities proposed by Benson (1992): Grey Box Woodland, Grey Box–Ironbark Woodland and Spotted Gum Forest. Instead, Cumberland Plain Woodlands were divided into two separate communities (Map Unit 10, Shale Plains Woodland and Map Unit 9, Shale Hills Woodland). A third shale woodland community was identified occurring on steep, sheltered slopes in the Razorback Range (Map Unit 14, Moist Shale Woodland). This community may not have been previously recognised. River Flat Forest as described by Benson (1992) was divided into three separate communities: Map Unit 11 (Alluvial Woodland), Map Unit 12 (Riparian Forest) and Map Unit 5 (Riparian Woodland). The first two of these communities correspond with a major dichotomy recognised by NPWS (1997) for alluvial areas draining shale-derived soils:'Cumberland Plain Creek Systems' and 'Hawkesbury–Nepean River and major Tributaries'. Riparian Woodland describes the assemblage of species found within creek lines and poorly drained areas on alluvial soils, and was included within the more extensively distributed alluvial communities by both Benson (1992) and NPWS (1997).

Western Shale Sandstone Transition Forest as described by NPWS (1997) was divided into two separate communities reflecting differences associated with variation in the level of sandstone influence (Map Units 1 and 2; Shale Sandstone Transition Forest (Low sandstone influence and High sandstone influence)). The Low Sandstone Influence variant is floristically similar to Benson and Howell's (1994b) Bargo Brush, however it is likely that these communities are sufficiently different to warrant recognition as distinct vegetation types. Eastern Shale Sandstone Transition Forest (NPWS 1997) was not recognised as a unique assemblage. Areas included by NPWS (1997) under this name fell within Map Unit 43 (Turpentine Ironbark Margin Forest) or Map Unit 3 (Castlereagh Ironbark Forest). Map Unit 13 (Western Sydney Dry Rainforest) was equivalent to the community of the same name described by NPWS (1997), and referred to as Rainforest Scrub by Benson (1992).

Patterns in community distribution: shale communities

Variation in floristic composition on shale soils was associated with regional gradients in elevation and rainfall, as well as local topographic variability and the degree of sandstone influence in the soil. Shale Plains Woodland (Map Unit 10) typically occurs on the flat, lower rainfall areas of the Cumberland Plain and grades into Shale Hills Woodland (Map Unit 9) at higher elevations in the southern half of the study area. Moist Shale Woodland (Map Unit 14) occurs at the upper end of the rainfall gradient, generally on the upper portion of very steep sheltered slopes, while Western Sydney Dry Rainforest (Map Unit 13) is frequently found in sheltered gullies. An overstorey dominated by either *Eucalyptus moluccana*, *E. tereticornis* or to a lesser extent *E. crebra* is typical throughout these communities.

On the eastern extremities of the Cumberland Plain, Shale Plains Woodland (Map Unit 10) grades into Turpentine Ironbark Forest (Map Unit 15) as annual rainfall increases above 950 mm. Ascending to the Hornsby Plateau, Turpentine Ironbark Forest grades into Blue Gum High Forest (Map Unit 152) as rainfall exceeds 1050 mm. This transition occurs at an altitude of approximately 100 m above sea level, although Turpentine Ironbark Forest is found at altitudes of up to 200 m on the western edge of the Hornsby Plateau where rainfall falls below 1050 mm. Floristic differences between these communities are not always reliably indicated by overstorey composition. Turpentine Ironbark forest may be dominated by *Eucalyptus saligna* at the upper end of its rainfall/elevation range, for example in Darvall Park and Denistone Park near Eastwood. Blue Gum High Forest is frequently dominated by *E. pilularis*.

Shale/sandstone transitional communities

A second gradient is apparent approaching the margins of the Plain and relates to an increase in the influence of sandstone in the soil associated with the diminishing thickness of the overlying shale stratum. Pigeon (1941) recognised this gradient as a shale/sandstone ecotone and noted the composition of the overstorey varied with location along the shale/sandstone boundary. A similar observation was made in NPWS (1997), where Shale Sandstone Transition Forest was recognised as a distinct assemblage, with a variable composition dependant on the composition of adjoining communities and the relative influence of shale and sandstone in the soil. Compositional patterns implying a sandstone influence were detected up to 1 km from the mapped location of the shale/sandstone interface. Within this zone the degree of sandstone influence increased with proximity to drainage zones, and with increasing stream order. While the ecotonal nature of shale/sandstone transition communities renders them more difficult to differentiate from adjoining communities, their conservation significance is highlighted by the fact that they contain species not recorded in samples of the adjoining shale and sandstone communities.

Clustering indicated floristic variation in the transitional zone warranted the recognition of three separate communities. Two communities were defined in areas receiving less than 950 mm rainfall annually. These reflected high and low levels of sandstone influence (Map Units 1 & 2). The boundary locations are somewhat arbitrary, and where a boundary between high and low sandstone influence is mapped the two communities are likely to be indistinguishable. The third community, Turpentine Ironbark Margin Forest (Map Unit 43) was recorded in areas of high sandstone influence and high rainfall, and was represented by sample sites on the edge of the Hornsby and Woronora Plateaus, and between Grose Vale and Bowen Mountain near Kurrajong. This community was floristically most similar to Map Unit 15 (Turpentine Ironbark Forest), but in areas of intermediate rainfall it is likely to be indistinguishable from Map Unit 2. Vegetation occurring on the shale capped ridges of the plateaus was not described in this survey, but it is floristically similar to Turpentine Ironbark Forest (Map Unit 15) as suggested by Benson (1992). Smaller shale remnants are likely to support transitional communities with a low sandstone influence, although none were sampled in this rainfall zone.

Communities occurring on Tertiary alluvium

Four communities were recognised occurring on two separate deposits of Tertiary alluvium in the north-west (Castlereagh) and south-east (Holsworthy) corners of the study area (Map Units 3, 4, 6 and 103). The distribution of these communities is possibly related to the extent of exposure of soils from three depositional phases (the St Marys, Rickabys Creek Gravel and Londonderry Clay formations) (Bannerman & Hazelton 1990), as well as local drainage conditions. Castlereagh Ironbark Forest (Map Unit 3) occurs on soils with a high clay content while Scribbly Gum Woodland (Map Unit 6) is more common on sandy loam soils. Soils with a high clay content underlie sandier soils but are exposed through erosion, especially towards the margins of the alluvial deposits. Scribbly Gum Woodland (Map Unit 6) thus tends to occur on slight rises (> 34 m ASL) deep in the heart of the alluvial deposits. The stand of Castlereagh Ironbark Forest (Map Unit 3) located in Castlereagh Nature Reserve was an exception to this rule, and possibly reflects a local occurrence of the Londonderry Clay Formation laid down in the third depositional phase. Castlereagh Swamp Woodland (Map Unit 4) occurs in poorly drained depressions in both the Holsworthy and Castlereagh areas. Small aeolian deposits in the vicinity of Agnes Banks support a distinct community of sclerophyllous species (Map Unit 8). Variability within this Map Unit was not well sampled in this survey, but was described by Benson (1981, 1992).

On the margins of the alluvial deposits, Castlereagh Ironbark Forest (Map Unit 3) grades into Shale/Gravel Transition Forest (Map Unit 103). As the name implies, this community has features characteristic of an ecotone, but unlike the Shale/Sandstone transitional communities it contains few unique species. Isolated deposits of Tertiary alluvium overlying Wianamatta Shale are mapped throughout the Cumberland plain (Bannerman & Hazelton 1990), and support stands of Shale/Gravel Transition Forest. This assemblage is also present in areas with a high concentration of iron-indurated gravels (laterite) (Benson & Howell 1994a). These gravels are highly resistant to weathering and may accumulate near the soil surface following long term erosion of the clay soils in which they are often embedded.

The few remaining remnants of native vegetation in the vicinity of Ashfield, Auburn and Bankstown have been the focus of some debate. Benson and Howell (1990) constructed a picture of the original vegetation of this area using documents predating the suburban development which took place after World War I. Several communities are thought to have occurred, including dense shrublands, probably dominated by *Melaleuca nodosa*, interspersed with woodland dominated by *Eucalyptus moluccana*, *E. fibrosa*, *E. longifolia* and *E. eugenioides*. A few isolated examples of this vegetation are located at Rookwood Cemetery, in the upper reaches of Salt Pan Creek and Norfolk Park, Greenacre (Benson and Howell 1990). Pure shale communities representative of both higher and lower rainfall areas are also thought to have been present, with patches of Western Sydney Dry Rainforest (Map Unit 13) occurring in sheltered localities (Benson and Howell 1990).

Remnant shrubland and ironbark woodland in this area has been ascribed to various communities. Benson and Howell (1994a) described such areas as Shale/Gravel Transition Forest. In the absence of mapped deposits of Tertiary alluvium, NPWS (1997) concluded they were better described as an eastern form of Shale/Sandstone Transition Forest. This classification recognised the close proximity of the shale/sandstone boundary, as well as outcrops of Minchinbury Sandstone between layers of shale. However, the Scientific Committees determination for the Endangered Ecological Community Shale/Sandstone Transition Forest noted that these areas were considered to be represented by another Endangered Ecological Community; namely, the Cooks River Clay Plain Scrub Forest. In the current survey, samples located at Rookwood Cemetery, Duck River, Norfolk Park (Greenacre), Carysfield Park (Bankstown) and Moorebank Brickworks clustered with sites recognised as Castlereagh Ironbark Forest (Map Unit 3). This is consistent with Benson and Howell's (1994a) observed floristic similarity between these areas and communities further west on Tertiary alluvium (which was the basis for their Shale/Gravel Transitional classification). Despite the isolation of these remnants, and the high potential for floristic anomalies relating to human disturbance, the floristic association with sites representative of Map Unit 3 was consistent, and sites sampled later in the survey joined the dendrogram in the same location. Therefore, despite the obvious structural differences (which may relate to past disturbances such as timber removal), this paper classes these areas as Castlereagh Ironbark Forest (Map Unit 3).

The distribution of these stands of Map Unit 3 around Bankstown and Auburn is correlated with the distribution of the Villawood Soil Series mapped by Walker (1960). The Villawood Series is a yellow podsolic soil extensively permeated with fine, concretionary ironstone (laterite). The link between Shale/Gravel Transition Forest and ironstone gravels has been previously noted (Benson & Howell 1994a). The distribution of the Villawood series accounts for the distribution of shrublands described in historical records

(Benson & Howell 1990) more satisfactorily than other features, such as the Birrong Soil Landscape. The Villawood Series is not differentiated in more recent soil maps (Chapman and Murphy 1989).

Riparian communities

Three communities were recognised occurring on soils of recent alluvial origin (Map Units 5, 11 & 12). Riparian Woodland (Map Unit 5) is confined to streamlines and adjacent swampy areas, and is floristically related to Map Unit 4 (Castlereagh Swamp Woodland). Riparian Woodland was not adequately sampled to enable its distribution to be mapped reliably. Riparian Forest (Map Unit 12) corresponds to communities occurring on the Hawkesbury–Nepean River and major Tributaries described in NPWS (1997), and includes the Camden White Gum Forest Community described by Benson (1992). Samples representative of Map Unit 12 were restricted to within 100 m of the Hawkesbury–Nepean and Georges Rivers. Historical accounts suggest that this assemblage may once have been more extensively distributed across the Hawkesbury–Nepean floodplains (Benson & Howell 1990), but in the absence of comprehensive data the floodplains have been mapped here as supporting Alluvial Woodland (Map Unit 11). This Map Unit corresponds to communities occurring on Cumberland Plain Creek Systems as described in NPWS (1997), but was sampled on major floodplains at distances greater than 100 m from the river. Toward the edge of the floodplain Alluvial Woodland grades into Shale Plains Woodland (Map Unit 10), and this latter assemblage may have occupied some parts of the floodplain. The modelled distribution of Alluvial Woodland may thus slightly overestimate the original extent of this assemblage.

Field identification of communities

Field identification of vegetation communities can be achieved by comparing the species composition, structure and characteristics of the physical environment to the community descriptions contained in Appendix 1. Since the community classification was based primarily on species composition, this provides the most reliable means of community diagnosis. Few communities can be identified on the basis of vegetation structure or the physical characteristics of the site alone, however these are useful for narrowing the field of possible choices.

Lists of species published under Endangered Ecological Community determinations (*TSC Act* 1995) and recent vegetation surveys (e.g. Keith & Bedward 1999) have proven difficult to utilise in the diagnosis of community type because no criteria exist to determine what minimum subset of species is required to confirm the presence of a community. This problem is addressed in this paper by specifying a minimum expected number of diagnostic species for each community based on individual species frequencies. The minimum expected numbers were calculated as the lower bound of a one-tailed 95% confidence interval. Thus a ‘true’ sample of a community type is expected to contain the minimum number of diagnostic species in 95% of cases. Conversely, in 5% of cases a ‘true’ sample will not contain sufficient diagnostic species; thus leading to the erroneous conclusion that the site does not belong to the community type in question.

Species count thresholds provide a practical method for applying diagnostic species lists in the identification of community type, however the presence/absence of diagnostic species can not be considered definitive. First, as outlined above, the procedure incorporates an explicit risk of error. Second, test sites frequently contain sufficient diagnostic species to qualify for more than one community type, typically two or three. In such cases the candidate communities usually display similarities in species composition and the test result may indicate that the test site fits any of the candidate communities equally well. This uncertainty reflects, in part, uncertainties inherent in classifying sites by cluster analysis, which is exemplified by the sensitivity of group composition to changes in analysis parameters and the composition of the data set. This problem may be particularly evident in the current study because the partitioning of ecotones resulted in the recognition of communities that frequently display only subtle differences in species composition. Communities may be more reliably identified if replicate test sites are surveyed in the area of interest.

Erroneous conclusions may arise due to sampling problems or if the method is incorrectly applied. First, probability estimates for those communities sampled by relatively few field sites (Communities 4, 5, 8, 12, 13, 34 & 35) are likely to be less accurate than for communities sampled more intensively. Second, threshold predictions are only valid for test sites of area 0.04 ha subject to the following conditions: (i) The test site must be located without bias: if the choice of location was made to either include or exclude particular species then the probability estimates will be invalid; (ii) The test site must be searched thoroughly and all vascular plant species present correctly identified. The majority of diagnostic species comprise herbs and grasses thus there is a high potential for community mis-identification through omission of species, particularly in seasons where reproductive material is not available or immediately following fire; (iii) The vegetation at the test site should not be modified in a way that is atypical of remnant vegetation on the Cumberland Plain. This condition is difficult to quantify, but is intended to exclude the use of the minimum species threshold for sites containing relatively few species in total. Species-poor sites may include those subject to repeated slashing, intensive grazing, soil disturbance or vandalism. A minimum species count has been included for each community; the diagnostic species threshold should not be applied unless this number is exceeded.

Accuracy

One of the principal objectives of this project was to provide a more accurate map of the native vegetation remnants of the Cumberland Plain and adjacent shale-topped plateaus. The features represented on the vegetation map may be interpreted at varying levels of detail and degree of accuracy is dependent on the spatial resolution at which the map is used. The boundaries of vegetation remnants were mapped with a high level of spatial accuracy. This can be demonstrated qualitatively by over-laying the vegetation boundaries on a base of certifiable accuracy such as the Land Information Centre 1:25 000 topographic maps. Keith et al. (2000) estimated the spatial error in locating remnant boundaries to be 20 m based on a comparison with digitally rectified aerial photographs.

The accuracy with which canopy cover classes were delineated is more difficult to quantify because a degree of subjectivity was involved in the interpretation. Based on an independent interpretation of photo-pattern for a subset of the study area (8836 ha), the area attributable to remnant native vegetation could vary between observers by as much as 1.9 ha for each kilometre of perimeter considered. Extrapolating this variation across the study area, the percentage of native vegetation extant is estimated to be between 10.7% and 15.4%. Further work is required to determine if this level of variation is typical for the interpretation of patterns in vegetation from aerial photographs. Nevertheless, these figures reinforce the fact that estimates of vegetation cover are subject to error due to a number of factors and should never be interpreted as absolute. The fact that sample sites were located in polygons of all classes (including cleared land) further highlights that fact that these classes are only an approximate representation of the condition of vegetation remnants.

The level of accuracy achieved in mapping the distribution of vegetation communities (95% within a radius of 500 m) was comparable with the results of other studies employing a decision tree approach (Keith & Bedward 1999, NPWS 2000). This level of accuracy implies that planning units chosen to include specific vegetation communities should be at least 79 ha in area to ensure a high probability that the community of interest is, in fact, contained in the unit. This requirement is likely to be largely unachievable on the Cumberland Plain because 97% of all remnants are estimated to be less than 79 ha in area. Although the map is the most reliable guide to the plant communities present in a site, rigorous field observations remain an essential component of map interpretation.

While the evenness and intensity of field sampling were of a relatively high level the distribution of some communities may have been less accurately modelled due to inadequate numbers of field samples. These include Dry Rainforest (Map Unit 13) and Moist Shale Woodland (Map Unit 14). These communities could be targeted more effectively if some index of topographic variability had been included in the sample stratification. The transition of vegetation communities from shale to sandstone soils could also be modelled more accurately if additional samples were stratified across topographic gradients in the zone of transition. However, gaps in the sample coverage were unavoidable due to high levels of clearing. The floodplains of the Hawkesbury–Nepean River were very poorly sampled for this reason. Some deficiencies in the spatial distribution of sampling were also apparent. Sampling intensity declined around the margins of the study area in part because of the additional travel time required to visit these areas. Map accuracy is likely to show a parallel decline, particularly at the northern and southern extremities of the study area. Communities occurring on Tertiary alluvium in the Castlereagh area were targeted for additional sampling in preparation for this revision. The additional samples greatly improved the accuracy of modelling, however further sampling would still be of benefit in describing this complex area.

The accuracy of the vegetation map was limited by the accuracy of the spatial data layers used in its compilation. Given the strong relationship between vegetation type and geological substrate, soil landscape maps of scale 1:100 000 were acknowledged *a priori* as a limiting factor for map accuracy. A considerable effort was made to overcome this limitation by using large-scale aerial photography to estimate tree canopy composition. This approach was based on the assumption that the distribution of tree species is aligned with the distribution of communities. In reality, there was considerable overlap in canopy composition between adjoining communities (Table 7) with the result that overstorey composition was of limited use in determining the location of boundaries. The extent to which overstorey composition was informative in compiling the map can be partially quantified. Only 12.7% of the total mapped area contained an overstorey species combination that was not recorded in the community type predicted to occur in that area by the spatial model. This high level of agreement between spatial model and API is consistent with the accuracy statistics over a 100–500 m radius. No simple assumptions can be made about the reliability of the model or API where they disagree. The area of the map for which community type was assigned based on overstorey composition alone was thus less than 12.7%.

For some communities, aerial photograph interpretation offers the most practical and efficient method of delineating boundaries accurately. For example, the distribution of wetlands (36) and, to a lesser extent, riparian communities (5, 11 & 12) was assisted by the availability of aerial photo-pattern. For other communities the interpretation of structural features could serve just as well as canopy composition for this purpose. Targeting specific communities and structural features with demonstrated application in the delineation of community boundaries is likely to be the most cost-effective strategy for aerial photograph interpretation. The significant costs associated with the estimation of canopy composition (large-scale photographs and extensive field reconnaissance) may not be justifiable if the utility of such data can not be demonstrated *a priori*. Given the overall contribution of aerial photo-pattern in compiling the Cumberland Plain vegetation map, it could be argued that aerial photograph interpretation consumed a disproportionate amount of resources (45% of the project budget).

Community conservation and remnant condition

The results of this survey provide a graphic illustration of the extent of depletion and fragmentation of the native vegetation of the Cumberland Plain and adjoining shale-capped plateaus. At the end of 1997, the remaining remnants accounted for only 13% of the original vegetation cover; a figure that has been further reduced by clearing over the ensuing five years. The overwhelming majority of remnants are small (< 79 ha), while many of the larger remnants exhibit a high ratio of perimeter length to area. Thus, there is a high potential for the future degradation of remnants through the impacts of activities on adjoining land and the invasion of weed species.

The high proportion of rare species recorded in field survey plots suggests that there is a high probability of loss of floristic diversity associated with any further clearing activity. Almost a quarter of all native species were recorded only once in the survey, while almost half were recorded five times or less. Loss of diversity is most likely to occur through the clearing of communities with highly restricted distributions such as Castlereagh Ironbark Forest (Map Unit 3) and Agnes Banks Woodland (Map Unit 8). Loss of diversity is also highly likely if further clearing occurs in the eastern part of the study area where native vegetation has been almost eliminated by urban and industrial development.

Few assumptions can be made about the condition of remnants based on the extent of *Eucalyptus* canopy cover as determined by API. Field sampling in this survey was biased toward remnants with high canopy cover while no attempt was made to sample areas with scattered or no tree cover (mapped TX, TXR and TXU). However, a significant proportion (10%) of the sites identified as high diversity remnants by field survey were subsequently classified as scattered or no tree cover by API, which suggests that this method may underestimate the extent of native vegetation communities, particularly secondary grasslands. While continuous tree cover was considered the best indicator for remnant native vegetation, field reconnaissance is essential to determine the conservation value of areas with scattered tree cover.

While it is frequently assumed that the conservation value of a remnant is proportional to its size, the results of this survey suggest that this assumption is inappropriate for conservation planning on the Cumberland Plain. First, small remnants constitute a large proportion of the remaining vegetation therefore the protection of these remnants is required to maintain vegetation cover at its present level. Second, although there was some evidence that small remnants were more susceptible to impacts from adjoining lands, many still contained a high diversity of native species and relatively few weeds. Third, given the large number of rare species recorded in the survey, the protection of all remnants is required to minimise the loss of floristic diversity. Avoiding the cumulative impacts caused by the clearing of small remnants is a significant challenge for biodiversity conservation on the Cumberland Plain.

While the protection of the remaining vegetation on the Cumberland Plain and adjoining plateaus remains a priority, several management problems also require urgent attention to assure the long-term conservation of biological diversity. First, two exotic plant species (*Olea europea* subsp. *africana*, and *Myrsiphyllum asparagoides*) were observed to be both widely dispersed and highly competitive, and appear to have the potential to suppress native understorey species. Second, research is required to identify fire regimes appropriate for the conservation of native biota. Third, the degradation of remnant vegetation through rubbish dumping and recreational vehicle damage is extensive and ongoing. It is undeniable that the prevention of further clearing and the establishment of effective weed and fire management strategies across all land tenures on the Cumberland Plain comprise a substantial challenge. Nevertheless, it is a sad fact that preventable degradation is ongoing.

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Appendix 1: Descriptions of Map Units

A list of diagnostic species has been compiled for all Map Units. For each species the following have been calculated:

- Cover/Abundance[1] within Map Unit (50 percentile): the median cover/abundance score recorded for the species in sites representing the Map Unit;
- Frequency (%) within Map Unit: the number of times the species was recorded in sites representing the Map Unit divided by the total number of sites representing the Map Unit;
- Cover/Abundance[1] in other Map Units (50 percentile): the median cover/abundance score recorded for the species in sites sampled in other Map Units.
- Frequency (%) within other Map Units: the number of times the species was recorded in sites representing other Map Units divided by the number of sites representing other Map Units;
- Fidelity class: positive (the species occurs more frequently in the Map Unit than in sites representing other Map Units; constant (the species occurs frequently within the Map Unit as well as sites representing other Map Units, and is therefore characteristic rather than diagnostic of the Map Unit); uninformative (the species does not occur frequently in the Map Unit nor in sites representing other Map Units).

[1]*Cover/abundance scores:*

1 = Rare, few individuals present AND cover < 5%
2 = Uncommon AND cover < 5%
3 = Common AND Cover < 5%
4 = (Very Abundant AND Cover < 5%) OR (5% ≤ Cover < 20%)
5 = (20% ≤ Cover <50%)
6 = (50% ≤ Cover <75%)
7 = (75% ≤ Cover < 100%)

Procedure for using positive diagnostic species for the identification of Map Unit type.

1. Determine the location of test plots using a random procedure. For example: Use a tape measure to define a grid then consult a table of random numbers to obtain coordinates for the location of the plots.
2. Mark out a search area of 0.04 ha (20 x 20 m is convenient) and record all vascular plant species with stems rooted within the search area.
3. Compile a shortlist of possible Map Unit types by comparing the vegetation structure and physical characteristics of the site with the descriptions contained in Appendix 1. The species composition of the test plot will be compared with each of these Map Unit types.
4. Count the number of **native** species occurring within the test plot. A minimum species count has been specified for each Map Unit type and is located in the diagnostic species table caption. The test can not proceed unless the test plot contains the minimum number of species specified for the Map Unit under consideration.
5. Considering each of the candidate Map Unit types in turn, consult the list of diagnostic species and count the number of species classified **positive** that were found in the test plot. The minimum expected number of positive diagnostic species has been specified for each Map Unit type and is located in the diagnostic species table caption. If the test plot contains the minimum number of positive diagnostic species ('pass') then it is a good match for that Map Unit type. A 'pass' result may be obtained for more than one of the candidate communities. In such cases the number of species by which the minimum was exceeded may be used to assess the closeness of the match to each of the possible candidates. A 'fail' result (the test plot contains fewer species than the expected minimum) does not exclude the possibility that the test plot is a match, however the fewer positive species recorded, the less likely it is that the Map Unit is a match (see discussion).

Map Unit 1:

Shale Sandstone Transition Forest (Low sandstone influence)

Sample sites: (38)
Area (ha) 1750 / 1997 (± range): 12834 / 1243 (±173)
Proportion extant (± range): 9.7 (±1.3)%
No. taxa (total / unique): 264 / 6
No. taxa per plot (±sd): 42.6 (±7.9)

Description:

Shale Sandstone Transition Forest (Low sandstone influence) is dominated by *Eucalyptus tereticornis*, with *E. eugenioides*, *E. crebra*, *E. fibrosa* and *E. punctata* occurring less frequently. A small tree stratum is usually present and dominated by *Eucalyptus* spp., with *Allocasuarina littoralis* and *Acacia decurrens* sometimes present. A shrub layer dominated by *Bursaria spinosa* is usually present, frequently this is of high density, although the foliage of this shrub is sparse and does not translate into high cover values. A diverse array of forb species is always present, frequently exceeding 50% in projected foliage cover. Species frequently present in the ground stratum include *Microlaena stipoides* var. *stipoides*, *Cheilanthes sieberi* subsp. *sieberi*, *Dichondra repens*, *Themeda australis*, *Echinopogon ovatus*, *Entolasia marginata*, *Pratia purpurascens*, *Solanum prinophyllum* and *Oxalis perennans*. Although this community marks the start of the transition from the pure shale communities of the Cumberland Plain to the surrounding sandstone communities, it contains relatively few species commonly observed on sandstone derived soils.

Shale Sandstone Transition Forest (Low sandstone influence) occurs around the margins of the Cumberland Plain on soils derived from Wianamatta Shale. It is most extensive in the south-eastern and south-western sections of the Study area. The community is only found in close proximity to a transition in parent geology from Wianamatta Shale to high-quartz sedimentary substrates such as the Hawkesbury and Narrabeen group Sandstones, as well as fine to medium grain quartz of the Mittagong formation. In these peripheral areas shale soils form a shallow layer over the underlying sandstone. The majority of sample sites were located within approximately 2 km of a sandstone/shale boundary. The community may also be found at greater distances from the sandstone/shale boundary where watercourses have eroded the shale stratum down close to the level of sandstone.

Shale Sandstone Transition Forest (Low sandstone influence) is typically found on the middle or upper slopes of gently undulating land. As distance to the sandstone/shale boundary increases Map Unit 1 grades into Map Unit 10 or, less frequently, Map Unit 9. The boundary between these communities is indistinct by nature, and Shale Sandstone Transition Forest includes areas with only a very slight influence of sandstone. As distance to the sandstone/shale boundary decreases, Map Unit 1 grades into Map Unit 2. Again, the boundary between these communities is indistinct and largely arbitrary.

Previous floristic classifications:

Map Units 1 and 2 combined correspond to the western form of Shale/Sandstone Transition Forest described in NPWS (1997) and subsequently listed under the *TSC Act* (1995). Eastern Shale/Sandstone Transition Forest (*sensu* NPWS (1997)) is herein included in Map Unit 3, an EEC listed under the name Cooks River/Castlereagh Ironbark Forest. Map Unit 43 also occurs on soils transitional between Shale and Sandstone, however this community is floristically most similar to Map Unit 15 and together they comprise the EEC Sydney Turpentine Ironbark Forest. Benson and Howell (1994b) described a Shale/Sandstone Transition Forest (Map Unit 9r) occurring on the sandstone side of the ecotone and this community is considered to fall outside the definition of Map Units 1, 2 and 43. However, Bargo Brush Forest (Benson and Howell 1994b, Map Unit 9mf) may fall within the definition of either Map Unit 1 or Map Unit 2.

Habitat:

Parent geology: Wianamatta Shale (98%), Holocene alluvium (2%)

	Mean	(±sd)	Range
Elevation (m)	146.8	(80.5)	1–360
Slope (° above horizontal)	4.2	(3.3)	0–14
Annual rainfall (mm)	847.1	(57.6)	764–941
Ruggedness (900m)	13.5	(6.8)	0–36
Maximum temperature Jan. (°C)	27.3	(0.6)	26–28
Solar radiation, January	214.7	(2.6)	207–219
Distance from sandstone derived soils (m)	879.1	(1080.6)	0–4650

Structure:

Growth form	Frequency (%)	Mean height (m)	(±sd)	Mean foliage cover (%)	(±sd)
Tree	100	23.0	(3.9)	24.1	(9.9)
Small tree	93	12.6	(3.9)	11.0	(8.2)
Shrub	88	3.3	(1.2)	16.1	(16.6)
Forb	100	0.8	(0.6)	49.7	(22.5)

Diagnostic species:

Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 12 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 33 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 12 positive diagnostic species.

C/A: Cover/Abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/Abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acacia decurrens	2	45	1	10	positive
Eucalyptus crebra	4	39	3	17	positive
Eucalyptus eugenioides	4	42	2	10	positive
Eucalyptus fibrosa	4	39	4	15	positive
Eucalyptus tereticornis	4	53	4	23	positive
Shrub stratum					
Bossiaea prostrata	1	29	1	6	positive
Hibbertia aspera	2	42	2	16	positive
Kunzea ambigua	2	45	2	15	positive
Leucopogon juniperinus	2	50	2	17	positive
Olearia viscidula	2	24	1	2	positive
Persoonia linearis	2	42	2	32	constant
Ground stratum					
Aristida vagans	2	53	2	44	constant
Brunoniella australis	2	68	3	32	positive
Bursaria spinosa	4	74	3	47	positive
Calotis dentex	3	34	2	4	positive
Cheilanthes sieberi subsp. *sieberi*	2	87	2	50	positive
Cymbopogon refractus	2	39	2	16	positive
Desmodium varians	2	63	2	33	positive
Dichondra repens	3	79	3	46	positive
Digitaria parviflora	2	37	2	9	positive
Echinopogon ovatus	2	87	2	29	positive
Entolasia marginata	2	76	2	23	positive
Eragrostis leptostachya	2	71	2	21	positive
Euchiton sphaericus	1	39	2	16	positive
Gahnia aspera	3	29	2	6	positive
Galium propinquum	2	39	2	8	positive
Lagenifera gracilis	2	42	2	13	positive
Lepidosperma laterale	2	63	2	44	constant
Lomandra confertifolia subsp. *rubiginosa*	2	32	3	8	positive
Microlaena stipoides var. *stipoides*	4	87	3	68	constant
Opercularia diphylla	2	53	2	34	constant
Oxalis perennans	2	66	2	25	positive
Panicum simile	2	42	2	33	constant
Pomax umbellata	2	42	2	35	constant
Poranthera microphylla	2	42	2	22	constant
Pratia purpurascens	2	76	2	42	positive
Solanum prinophyllum	2	76	2	24	positive
Themeda australis	3	76	3	56	constant
Tricoryne elatior	2	34	2	14	positive
Veronica plebeia	2	68	2	20	positive
Climbers					
Glycine clandestina	2	47	2	42	constant
Glycine tabacina	2	53	2	25	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora bakeri	4	3	2	14	uninform.
Angophora floribunda	1	16	2	7	uninform.
Corymbia gummifera	2	3	2	30	uninform.
Corymbia maculata	4	11	4	3	uninform.
Eucalyptus globoidea	4	13	2	8	uninform.
Eucalyptus moluccana	4	24	4	19	uninform.
Eucalyptus pilularis	5	3	4	14	uninform.
Eucalyptus punctata	4	34	3	24	uninform.
Eucalyptus resinifera	4	5	1	4	uninform.
Eucalyptus saligna	4	3	3	3	uninform.
Eucalyptus sideroxylon	4	3	3	1	uninform.
Syncarpia glomulifera	4	5	3	21	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Olea europaea subsp. *africana*	1	41	2	26	constant
Ground stratum					
Cirsium vulgare	2	43	1	33	constant
Plantago lanceolata	2	41	2	25	constant
Senecio madagascariensis	2	54	2	52	constant

Map Unit 2:

Shale Sandstone Transition Forest (High sandstone influence)

Sample Sites: 70
Area (ha) 1750 / 1997 (± range): 32521 / 8717 (±912)
Proportion Extant (± range): 26.8 (±2.8)%
No. Taxa (total / unique): 380 / 15
No. Taxa per Plot (±sd): 49.5 (±8.1)

Shale Sandstone Transition Forest (High sandstone influence) is dominated by *Eucalyptus punctata* and *E. crebra*, with *E. fibrosa*, *Corymbia gummifera* and *Syncarpia glomulifera* occurring less frequently. A smaller tree stratum is usually present and is most often dominated by *Allocasuarina littoralis*, *Syncarpia glomulifera*, *Persoonia linearis* and *Acacia decurrens*. Map Unit 2 usually has a well-developed shrub layer which is more diverse in species than in communities with less sandstone influence in the soil. The shrub stratum is dominated by *Kunzea ambigua*, *Persoonia linearis* and *Bursaria spinosa*, with *Jacksonia scoparia* becoming more common with increasing sandstone influence. The ground stratum is dominated by *Entolasia stricta*, *Themeda australis*, *Stipa pubescens*, *Lepidosperma laterale*, *Aristida vagans* and *Pomax umbellata*.

Map Unit 2 occurs on the margins of the Cumberland Plain in close proximity to the sandstone/shale boundary, and is most extensively distributed in the south-western and south-eastern sectors of the study area. It is also found on the northern and north western margins of the Cumberland Plain but was not well sampled in those areas in this study. The majority of sample sites for this community were located within

400 m of the shale/sandstone boundary and varied considerably in the degree of sandstone influence evident in the soil. Map Unit 2 is essentially a shale community, and is most likely to occur on shallow, residual clay soils derived from Wianamatta Shale. However, it may also be found on high-quartz sandstone-derived soils where there is a strong colluvial shale influence (eg the upper slopes of sandstone gullies adjoining shale soils), and on outcrops of pure shale soils derived from the Mittagong Formation. Map Unit 2 occurs primarily on upper slopes and ridges on gently undulating terrain.

Map Unit 2 grades into Map Unit 1 with increasing distance from the sandstone/shale boundary. If the transition is abrupt, then Map Unit 2 may grade directly into Map Unit 10. Along the western edge of the Georges River Map Unit 2 makes an abrupt transition into sandstone communities and there is a pronounced change in floristic composition.

Previous floristic classifications:

Shale Sandstone Transition Forest (High sandstone influence) is one of two communities which together correspond to Shale Sandstone Transition Forest as listed under the *TSC Act* (1995). Further discussion is included under the description of Map Unit 1.

Habitat:

Parent Geology: Wianamatta Shale (53%), Mittagong Formation (31%), Hawkesbury Sandstone (16%)

	Mean	(±sd)	Range
Elevation (m)	146.3	(78.2)	14–393
Slope (° above horizontal)	4.2	(3.9)	0–17.7
Annual Rainfall (mm)	880.0	(46.1)	756–981
Ruggedness (900m)	12.3	(6.8)	4–43
Maximum Temperature, Jan. (°C)	27.3	(7.0)	26.3–28.9
Solar Radiation, January	215.0	(2.6)	204–220
Distance from sandstone derived soils (m)	132.8	(234.1)	0–1398.7

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	21.1 (4.4)	19.9 (9.9)
Small Tree	84	10.1 (4.0)	10.9 (9.1)
Shrub	91	3.2 (1.3)	11.6 (10.6)
Forb	96	0.7 (0.7)	33.8 (21.3)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 20 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 40 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 20 positive diagnostic species.

C/A: Cover/Abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/Abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acacia binervata	2	14	1	1	positive
Acacia decurrens	2	24	1	11	positive
Allocasuarina littoralis	2	50	2	22	positive
Angophora bakeri	1	27	3	12	positive
Corymbia maculata	4	13	4	3	positive
Eucalyptus crebra	3	57	4	14	positive
Eucalyptus fibrosa	4	39	4	14	positive
Eucalyptus punctata	3	61	2	20	positive
Exocarpos cupressiformis	1	26	1	11	positive
Shrub stratum					
Acacia falcata	1	23	1	10	positive
Bursaria spinosa	2	60	3	47	constant
Exocarpos strictus	2	30	2	9	positive
Gompholobium species *B*	2	10	2	2	positive
Hibbertia aspera	2	40	2	15	positive
Hibbertia diffusa	2	36	2	13	positive
Jacksonia scoparia	2	29	1	3	positive
Kunzea ambigua	2	60	2	12	positive
Leucopogon juniperinus	2	47	2	16	positive
Leucopogon muticus	2	13	1	2	positive
Notelaea longifolia f. *longifolia*	1	31	1	16	positive
Olearia microphylla	1	17	1	6	positive
Ozothamnus diosmifolius	2	63	1	25	positive
Persoonia linearis	2	84	2	27	positive
Phyllanthus hirtellus	2	53	2	32	positive
Pimelea linifolia subsp. *linifolia*	2	59	2	25	positive
Pomaderris lanigera	2	10	1	1	positive
Ground stratum					
Aristida vagans	2	90	2	40	positive
Astroloma humifusum	1	20	1	6	positive
Billardiera scandens	2	71	1	34	positive
Calotis dentex	2	26	2	4	positive
Cheilanthes sieberi subsp. *sieberi*	2	81	2	49	positive
Dampiera purpurea	2	13	1	4	positive
Desmodium rhytidophyllum	1	14	1	5	positive
Dianella caerulea	2	44	2	27	constant
Dianella revoluta var. *revoluta*	2	54	2	36	positive
Dichelachne micrantha	2	47	2	30	constant
Digitaria ramularis	2	39	1	4	positive
Echinopogon caespitosus var. *caespitosus*	2	73	2	21	positive
Entolasia stricta	3	90	3	55	positive
Eragrostis brownii	2	39	2	19	positive
Gahnia aspera	1	20	2	6	positive
Gonocarpus tetragynus	2	44	2	20	positive
Goodenia hederacea subsp. *hederacea*	2	49	2	32	constant
Lagenifera gracilis	2	40	2	12	positive
Laxmannia gracilis	1	39	2	15	positive
Lepidosperma laterale	3	90	2	40	positive
Lomandra filiformis subsp. *coriacea*	2	34	2	13	positive
Lomandra multiflora subsp. *multiflora*	2	87	2	46	positive
Microlaena stipoides var. *stipoides*	3	83	3	68	constant
Notodanthonia longifolia	2	11	2	1	positive
Opercularia diphylla	2	54	2	33	positive
Panicum simile	2	79	2	29	positive
Paspalidium distans	2	40	2	25	constant
Poa labillardieri var. *labillardieri*	2	37	2	15	positive
Pomax umbellata	2	84	2	30	positive
Pratia purpurascens	2	74	2	40	positive
Pterostylis concinna	2	9	–	0	positive
Solanum prinophyllum	1	46	2	25	positive
Stipa pubescens	3	56	2	24	positive
Stypandra glauca	2	30	1	2	positive
Themeda australis	3	80	3	54	positive
Veronica plebeia	1	41	2	21	positive
Climbers					
Glycine clandestina	2	77	2	38	positive
Hardenbergia violacea	2	47	1	29	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora costata	1	10	2	20	uninform.
Angophora floribunda	2	9	2	8	uninform.
Corymbia eximia	3	7	2	3	uninform.
Corymbia gummifera	2	29	3	29	uninform.

Eucalyptus agglomerata	1	1	2	2	uninform.
Eucalyptus beyeriana	2	1	–	0	uninform.
Eucalyptus eugenioides	4	19	2	11	uninform.
Eucalyptus globoidea	2	17	2	7	uninform.
Eucalyptus haemastoma	4	1	2	3	uninform.
Eucalyptus longifolia	4	4	1	2	uninform.
Eucalyptus moluccana	1	1	4	21	uninform.
Eucalyptus notabilis	1	4	2	5	uninform.
Eucalyptus oblonga	3	16	2	8	uninform.
Eucalyptus paniculata	1	1	2	3	uninform.
Eucalyptus pilularis	1	14	4	13	uninform.
Eucalyptus resinifera	1	7	1	4	uninform.
Eucalyptus sclerophylla	4	6	4	9	uninform.
Syncarpia glomulifera	4	27	3	19	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Ground stratum					
Senecio madagascariensis	1	44	2	53	constant

Map Unit 3:

Castlereagh Ironbark Forest

Sample Sites: (28)
Area (ha) 1750 / 1997 (± range): 12211 /1012 (±99)
Proportion Extant (± range): 8.3 (±0.8)%
No. Taxa (total / unique): 227/4
No. Taxa per Plot (±sd): 41.3 (±5.4)

Castlereagh Ironbark Forest is dominated by *Eucalyptus fibrosa* and *Melaleuca decora*, with *E. longifolia* occurring at lower frequency. The height of the overstorey is relatively variable and often merges into a smaller tree stratum dominated by the same species. A relatively dense shrub stratum is typical, and dominated by *M. nodosa* and *Lissanthe strigosa*, and to a lesser extent *M. decora*. A variety of shrub species occur at relatively low frequencies, including *Acacia pubescens*, *Dillwynia tenuifolia*, *Daviesia ulicifolia*, *Pultenaea villosa* and *Grevillea juniperina*. The ground stratum is relatively sparse compared to adjoining communities on Tertiary alluvium or shale soils. Commonly occurring species include *Entolasia stricta*, *Lepidosperma laterale*, *Opercularia diphylla*, *Dianella revoluta* subsp. *revoluta*, *Themeda australis*, *Microlaena stipoides* var. *stipoides* and *Pratia purpurascens*.

Castlereagh Ironbark Forest primarily occurs on clay soils derived from Tertiary alluvium, or on shale soils adjacent to the boundary with Tertiary alluvium. The most extensive stands occur in the Castlereagh and Holsworthy areas. A small patch occurs adjacent to Kemps Creek on an isolated fragment of Tertiary alluvium. Where the Tertiary alluvium is shallow, Map Unit 3 grades into Map Unit 103. This transition is difficult to predict and may be influenced by other factors such as drainage. In very poorly drained depressions Map Unit 3 grades into Map Unit 4. Where the soil is sandier Map Unit 3 grades into Map Unit 6. In the Castlereagh area this often occurs with increasing elevation.

Highly modified remnants of this community occur in the vicinity of Bankstown and exhibit atypical structure: the tree stratum is shorter or absent and dominated by *E. fibrosa*, *E. longifolia* or more rarely *Angophora floribunda* and *E. oblonga*. The shrub stratum was often dense, particularly in the absence of overstorey, and dominated by *Melaleuca nodosa* and *Bursaria spinosa*. These remnants are apparently remote from deposits of Tertiary alluvium, but occur in an area described as having a high concentration of iron-indurated gravel in the soil (Villawood Soil Series; Walker 1960) (See Discussion). Slight floristic differences between sample sites in this area and sample sites further to the west and south-west may be due to the higher influence of shale in the soil or higher rainfall. The highly modified and isolated nature of these remnants is also likely to have contributed to floristic differences.

Previous floristic classifications:

Castlereagh Ironbark Forest corresponds to the community of the same name described by Benson (1992), (Map Unit 9c), and NPWS (1997), although differences exist in the extent of distribution recognised. These differences are primarily related to problems associated with classifying sites in a zone of transitional vegetation, and mainly involve areas being recognised as Castlereagh Ironbark Forest by one author and transitional by another.

Castlereagh Ironbark Forest includes part of the vegetation classified as eastern Shale/Sandstone Transition Forest (NPWS 1997) and that formerly listed under the *TSC Act* (1995) as Cooks River Clay Plain Scrub Forest. This listing was revised to include Map Unit 3 in its entirety under the name Cooks River/Castlereagh Ironbark Forest. This survey distinguished remnants of both Shale Sandstone Transition Forest (Map Units 1 and 2) and Castlereagh Ironbark Forest between Bankstown and Strathfield.

Habitat:

Parent Geology: Tertiary alluvium (52%), Holocene alluvium (18%), Wianamatta Shale (30%)

	Mean (±sd)	Range
Elevation (m)	28.7 (16.5)	1– 61
Slope (° above horizontal)	1.1 (0.8)	0– 2.3
Annual Rainfall (mm)	853.6 (53.5)	799–960
Ruggedness (900m)	3.3 (1.1)	1–5
Maximum temperature, Jan. (°C)	27.9 (0.8)	26.7–29.1
Solar radiation, January	217.4 (1.0)	216–219

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	20.0 (7.5)	18.9 (11.0)
Small Tree	74	10.9 (4.0)	14.3 (10.8)
Shrub	100	3.7 (2.2)	34.8 (23.4)
Forb	100	0.4 (0.5)	17.9 (15.1)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 14 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 34 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 14 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Eucalyptus fibrosa	4	82	3	14	positive
Eucalyptus longifolia	1	29	2	1	positive
Melaleuca decora	4	89	3	9	positive
Shrub stratum					
Acacia elongata	2	29	2	3	positive
Acacia falcata	1	50	1	9	positive
Acacia pubescens	3	25	–	0	positive
Bursaria spinosa	2	46	3	49	constant
Daviesia ulicifolia	2	50	2	14	positive
Dillwynia tenuifolia	3	46	3	3	positive
Dodonaea falcata	3	21	–	0	positive
Lissanthe strigosa	3	68	2	19	positive
Melaleuca nodosa	4	82	3	7	positive
Olearia microphylla	1	43	1	6	positive
Ozothamnus diosmifolius	1	68	2	27	positive
Pultenaea parviflora	3	39	–	0	positive
Ground stratum					
Aristida vagans	2	71	2	44	positive

Austrodanthonia tenuior	2	61	2	14	positive
Calotis cuneifolia	2	21	2	2	positive
Cheilanthes sieberi subsp. *sieberi*	2	89	2	50	positive
Dianella revoluta var. *revoluta*	2	82	2	36	positive
Dichelachne micrantha	1	43	2	31	constant
Entolasia stricta	3	96	3	57	positive
Eragrostis brownii	2	54	2	19	positive
Goodenia hederacea subsp. *hederacea*	2	61	2	32	positive
Lagenifera stipitata	3	36	2	4	positive
Laxmannia gracilis	2	61	1	16	positive
Lepidosperma laterale	3	93	2	43	positive
Lomandra multiflora subsp. *multiflora*	2	71	2	49	constant
Microlaena stipoides var. *stipoides*	3	93	3	68	positive
Opercularia diphylla	3	79	2	33	positive
Panicum simile	2	61	2	32	positive
Paspalidium distans	2	61	2	25	positive
Pomax umbellata	3	57	2	34	constant
Pratia purpurascens	3	79	2	42	positive
Themeda australis	3	54	3	57	constant
Thysanotus tuberosus subsp. *tuberosus*	2	29	1	6	positive
Vernonia cinerea var. *cinerea*	2	54	2	17	positive
Climbers					
Cassytha glabella f. *glabella*	2	46	2	15	positive
Glycine clandestina	2	46	2	42	constant

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora bakeri	2	7	2	13	uninform.
Angophora floribunda	4	7	2	8	uninform.
Angophora subvelutina	1	4	4	3	uninform.
Eucalyptus crebra	1	4	3	18	uninform.
Eucalyptus eugenioides	1	14	2	11	uninform.
Eucalyptus globoidea	3	4	2	8	uninform.
Eucalyptus moluccana	2	7	4	20	uninform.
Eucalyptus oblonga	4	4	2	9	uninform.
Eucalyptus parramattensis subsp. *parramattensis*	1	7	2	4	uninform.
Eucalyptus resinifera	4	4	1	4	uninform.
Eucalyptus sclerophylla	3	7	4	9	uninform.
Eucalyptus sideroxylon	1	4	4	1	uninform.
Eucalyptus tereticornis	1	7	4	25	uninform.
Syncarpia glomulifera	2	7	3	21	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Ground stratum					
Hypochaeris radicata	1	41	2	32	constant
Senecio madagascariensis	2	41	2	52	constant

Map Unit 103:

Shale Gravel Transition Forest

Sample Sites: (25)
Area (ha) 1750 / 1997 (± range): 5427 / 1721 (±170)
Proportion Extant (± range): 31.7 (±3.1)%
No. Taxa (total / unique): 216 / 1
No. Taxa per Plot (±sd): 45.1 (7.1)

Shale Gravel Transition Forest is usually dominated by *Eucalyptus fibrosa* with *E. moluccana* and *E. tereticornis* occurring less frequently, but sometimes dominating in the absence of *E. fibrosa*. *Melaleuca decora* is frequently present in a small tree stratum. A sparse shrub stratum is usually present and typically includes species such as *Bursaria spinosa*, *Daviesia ulicifolia* and *Lissanthe strigosa*. A variety of forb species were recorded with high frequency, including *Microlaena stipoides* subsp. *stipoides*, *Cheilanthes sieberi* subsp. *sieberi*, *Themeda australis*, *Opercularia diphylla*, *Lomandra multiflora* subsp. *multiflora*, *Aristida vagans*, *Pratia purpurascens* and *Wahlenbergia gracilis*.

Shale Gravel Transition Forest occurs primarily in areas where shallow deposits of Tertiary alluvium overlie shale soils, but also in association with localised concentrations of iron-indurated gravel. Ironstone accretions are more resistant to weathering than shale and may become concentrated on ridgelines through the long-term erosion of shale. This community is likely to have been found in the Auburn–Bankstown area in association with the gravels of the Villawood soil series (Walker 1960), although native vegetation in this area has been extensively cleared. Shale Gravel Transition Forest grades into Map Unit 10 as alluvial and ironstone influences decline. On thicker deposits of Tertiary alluvium it grades into Map Units 3 or 6. South of the Tertiary alluvial deposits at Holsworthy, this community apparently occurs on soils of the Mittagong Formation, and forms complex mosaics with shale/sandstone transitional communities.

Previous floristic classifications:

Shale Gravel Transition Forest corresponds to the community of the same name described by Benson (1992), (Map Unit 9d), and NPWS (1997), although differences exist in the extent of distribution recognised. These differences are primarily related to problems associated with classifying sites in a zone of transitional vegetation, and mainly involve areas being recognised as Castlereagh Ironbark Forest by one author and transitional by another.

Habitat:

Parent Geology: Tertiary alluvium (47%), Mittagong Formation (30%), Wianamatta Shale (14%), Holocene alluvium (3%), Aeolian Deposits (3%), Hawkesbury sandstone (3%)

	Mean (±sd)	Range
Elevation (m)	35.3 (16.8)	19–78
Slope (° above horizontal)	1.6 (1.8)	0–7.4
Annual Rainfall (mm)	845.3 (50.9)	788–968
Ruggedness (900m)	5.4 (5.7)	2–31
Maximum Temperature, Jan (°C)	28.0 (0.7)	26.9–29.0
Solar Radiation, January	217.0 (0.7)	215–218

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	21.9 (2.4)	20.3 (10.4)
Small Tree	68	11.2 (3.0)	8.4 (5.9)
Shrub	76	3.3 (1.5)	13.6 (14.5)
Forb	100	0.6 (0.5)	44.6 (24.6)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 15 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 37 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 15 positive diagnostic species.

C/A: Cover/Abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/Abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acacia parramattensis	2	40	2	22	constant
Eucalyptus fibrosa	4	64	4	15	positive
Eucalyptus moluccana	4	40	4	19	constant
Eucalyptus tereticornis	4	40	4	24	constant

Melaleuca decora	4	64	3	10	positive
Shrub stratum					
Acacia falcata	1	40	1	10	positive
Bursaria spinosa	3	84	3	47	positive
Daviesia ulicifolia	2	68	2	14	positive
Dillwynia sieberi	3	24	2	6	positive
Lissanthe strigosa	2	52	2	20	positive
Pultenaea villosa	2	20	2	3	positive
Ground stratum					
Agrostis avenacea var. *avenacea*	1	36	1	7	positive
Aristida vagans	2	88	2	43	positive
Austrodanthonia tenuior	3	52	2	15	positive
Brunoniella australis	3	60	3	33	constant
Calotis cuneifolia	2	20	2	3	positive
Cheilanthes sieberi subsp. *sieberi*	3	92	2	50	positive
Chorizema parviflorum	2	28	1	1	positive
Desmodium varians	3	68	2	33	positive
Dianella longifolia	2	52	2	18	positive
Dianella revoluta var. *revoluta*	3	56	2	37	constant
Dichelachne micrantha	3	68	2	30	positive
Dichondra repens	3	68	3	47	constant
Echinopogon caespitosus var. *caespitosus*	2	48	2	25	constant
Echinopogon ovatus	2	52	2	31	constant
Entolasia stricta	3	80	3	58	constant
Euchiton sphaericus	1	40	2	16	constant
Fimbristylis dichotoma	2	28	2	7	positive
Goodenia hederacea subsp. *hederacea*	2	68	2	32	positive
Hydrocotyle peduncularis	2	44	2	8	positive
Hypericum gramineum	2	56	2	18	positive
Lagenifera stipitata	3	24	2	4	positive
Laxmannia gracilis	2	52	1	16	positive
Lepidosperma laterale	3	56	2	44	constant
Lomandra filiformis subsp. *filiformis*	3	68	2	33	positive
Lomandra multiflora subsp. *multiflora*	2	92	2	49	positive
Microlaena stipoides var. *stipoides*	3	100	3	68	positive
Opercularia diphylla	3	96	2	33	positive
Oxalis perennans	2	56	2	26	positive
Panicum simile	3	56	2	33	constant
Paspalidium distans	2	44	2	26	constant
Pomax umbellata	3	52	2	35	constant
Poranthera microphylla	3	72	2	21	positive
Pratia purpurascens	2	84	2	42	positive
Themeda australis	4	84	3	56	positive
Thysanotus tuberosus subsp. *tuberosus*	2	28	1	6	positive
Tricoryne elatior	3	52	2	14	positive
Vernonia cinerea var. *cinerea*	2	52	2	17	positive
Wahlenbergia gracilis	2	76	2	28	positive
Climbers					
Glycine clandestina	2	68	2	41	constant
Hardenbergia violacea	2	48	1	30	constant
Polymeria calycina	2	24	1	5	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora bakeri	4	4	2	13	uninform.
Angophora floribunda	4	8	2	8	uninform.
Angophora subvelutina	1	4	4	3	uninform.
Corymbia maculata	1	4	4	4	uninform.
Eucalyptus crebra	4	36	3	17	uninform.
Eucalyptus eugenioides	1	24	2	11	uninform.
Eucalyptus globoidea	3	12	2	8	uninform.
Eucalyptus punctata	4	8	3	25	uninform.
Eucalyptus sclerophylla	4	8	4	9	uninform.
Eucalyptus sparsifolia	5	4	3	4	uninform.
Syncarpia glomulifera	1	4	3	21	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Ground stratum					
Centaurium tenuiflorum	1	40	1	9	positive
Cirsium vulgare	1	44	1	34	constant
Gamochaeta americana	1	32	1	8	positive
Gamochaeta calviceps	1	28	1	5	positive
Hypochaeris radicata	2	52	1	31	constant
Senecio madagascariensis	1	84	2	50	positive
Sisymbrium species A	1	28	2	3	positive
Sonchus oleraceus	1	48	1	21	positive

Map Unit 4:

Castlereagh Swamp Woodland

Sample Sites: (7)
Area (ha) 1750 / 1997 (± range): 1006 / 616 (±27)
Proportion Extant (± range): 61.2 (±2.7)%
No. Taxa (total / unique): 145 / 12
No. Taxa per Plot (±sd): 44.0 (9.1)

Castlereagh Swamp Woodland is dominated by medium to dense stands of *Melaleuca decora* ranging in height from shrubs of 2–4 m to trees of 15–20 m. *Eucalyptus fibrosa*, *Angophora subvelutina* and *Melaleuca linariifolia* are present less frequently in both the tree and small tree strata. *Eucalyptus parramattensis* subsp. *parramattensis* is frequently present, but is usually represented by only a few individuals. Map Unit 4 has a poorly developed shrub layer consisting of young individuals of *M. decora*, *M. linariifolia* and, less frequently, *Bursaria spinosa* at low cover/abundance. The Ground stratum is often dense and diverse, and includes species tolerant of water-logged conditions such as *Goodenia paniculata*, *Schoenus apogon*, *Centella asiatica* and *Juncus usitatus*.

Castlereagh Swamp Woodland occurs in poorly drained depressions on soils derived from Tertiary alluvium, or on adjacent shale soils where the influence of Tertiary alluvium is strong. Its distribution is highly restricted, with the two main examples occurring in the Castlereagh and Holsworthy areas. Map Unit 4 was also identified at a sample site in the vicinity of Tertiary Alluvial deposits at Kemps Creek. An outlying sample is located north of Camden near the Nepean River, possibly related to Tertiary alluvium associated with the Theresa Park soil landscape. In better drained areas Map Unit 4 grades into Map Unit 6 and sometimes into Map Unit 3.

Previous floristic classifications:

Castlereagh Swamp Woodland corresponds to the community of the same name described by Benson (1992), (Map Unit 14c), and NPWS (1997), although differences exist in the extent of distribution recognised. In particular, this community is more restricted in distribution than previously described in the Castlereagh area. Castlereagh Swamp Woodland is listed as an Endangered Ecological Community under the NSW Threatened Species Act.

Habitat:

Parent Geology: Tertiary alluvium (57%), Wianamatta Shale (29%), Aeolian Deposits (14%)

	Mean (±sd)	Range
Elevation (m)	30.1 (17.8)	12–60
Slope (° above horizontal)	1.5 (3.1)	0–8.4
Annual Rainfall (mm)	807.4 (47.3)	729–871
Ruggedness (900m)	3.1 (2.7)	1–9
Maximum Temperature, Jan. (°C)	28.3 (7.0)	27.4–29.1
Solar Radiation, January	21.7 (0.1)	216–218

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	17.6 (5.1)	24.0 (19.4)
Small Tree	57	11.5 (1.0)	17.5 (9.6)
Shrub	100	4.1 (1.7)	5.9 (4.2)
Forb	86	0.7 (0.5)	53.2 (35.2)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 12 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 34 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 12 positive diagnostic species.

C/A: Cover/Abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/Abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora subvelutina	4	29	4	2	positive
Eucalyptus parramattensis subsp. *parramattensis*	1	57	2	3	positive
Melaleuca decora	5	86	3	11	positive
Melaleuca linariifolia	3	43	1	2	positive
Shrub stratum					
Bursaria spinosa	2	43	3	49	constant
Melaleuca thymifolia	1	29	2	2	positive
Ground stratum					
Agrostis avenacea var. *avenacea*	3	71	1	8	positive
Alternanthera denticulata	2	29	1	2	positive
Aristida vagans	1	43	2	45	constant
Austrodanthonia tenuior	1	57	2	16	constant
Brunoniella pumilio	2	43	2	19	constant
Centella asiatica	3	86	2	10	positive
Centipeda minima var. *minima*	2	43	2	1	positive
Cheilanthes sieberi subsp. *sieberi*	2	86	2	51	constant
Dianella longifolia	1	43	2	19	constant
Dichelachne micrantha	2	43	2	31	constant
Dichondra repens	2	71	3	47	constant
Entolasia stricta	3	57	3	59	constant
Epaltes australis	2	43	2	1	positive
Eragrostis brownii	2	57	2	20	constant
Eragrostis elongata	1	29	1	1	positive
Eragrostis leptostachya	2	43	2	23	constant
Euchiton gymnocephalum	2	29	1	1	positive
Euchiton sphaericus	1	43	2	17	constant
Fimbristylis dichotoma	3	57	2	7	positive
Goodenia paniculata	3	100	2	2	positive
Gratiola pedunculata	2	71	–	0	positive
Haloragis heterophylla	4	29	2	1	positive
Hemarthria uncinata var. *uncinata*	2	29	1	1	positive
Hydrocotyle peduncularis	3	71	2	9	positive
Hypericum gramineum	2	71	2	19	positive
Hypoxis hygrometrica	2	57	2	10	positive
Isolepis inundata	4	43	2	1	positive
Juncus planifolius	3	43	2	1	positive
Juncus prismatocarpus	3	29	–	0	positive
Juncus usitatus	3	86	1	9	positive
Lepyrodia muelleri	4	43	–	0	positive
Lomandra longifolia	4	57	2	32	constant
Lomandra multiflora subsp. *multiflora*	2	71	2	50	constant
Lythrum hyssopifolia	3	43	–	0	positive
Microlaena stipoides var. *stipoides*	3	86	3	69	constant
Opercularia diphylla	2	86	2	34	positive
Panicum simile	2	43	2	33	constant
Paspalidium distans	1	71	2	26	constant
Paspalum orbiculare	1	43	–	0	positive
Poranthera microphylla	2	71	2	23	positive
Pratia purpurascens	3	86	2	43	constant
Schoenus apogon	2	100	1	2	positive
Themeda australis	2	86	3	57	constant
Tricoryne elatior	2	43	2	15	constant
Wahlenbergia gracilis	1	43	2	30	constant
Wurmbea dioica subsp. *dioica*	4	29	2	2	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora floribunda	4	14	2	8	uninform.
Eucalyptus amplifolia	1	29	4	4	uninform.
Eucalyptus eugenioides	1	14	2	11	uninform.
Eucalyptus fibrosa	4	29	4	16	uninform.
Eucalyptus sclerophylla	1	14	4	9	uninform.
Eucalyptus sideroxylon	4	14	3	1	uninform.
Eucalyptus tereticornis	4	29	4	24	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Ground stratum					
Andropogon virginicus	3	29	1	1	positive
Aster subulatus	1	43	1	3	positive
Briza minor	2	43	2	1	positive
Centaurium erythraea	1	29	2	2	positive
Ciclospermum leptophyllum	2	43	1	10	constant
Cyperus eragrostis	2	29	2	2	positive
Gamochaeta calviceps	1	43	1	6	positive
Gamochaeta calviceps	1	28	1	5	positive
Hypochaeris radicata	3	71	1	31	constant
Paspalum urvillei	4	29	2	2	positive
Plantago lanceolata	2	43	2	26	constant
Senecio madagascariensis	3	57	2	52	constant
Setaria gracilis	3	71	2	25	constant
Sisymbrium species *A*	1	28	2	3	positive
Sonchus oleraceus	1	71	1	21	positive

Map Unit 6:

Castlereagh Scribbly Gum Woodland

Sample sites: (26)
Area (ha) 1750 / 1997 (± range): 5852 / 3083 (±171)
Proportion extant (± range): 52.7 (±2.9)%
No. taxa (total / unique): 226 / 13
No. taxa per Plot (±sd): 48.8 (±7.2)

Castlereagh Scribbly Gum Woodland is dominated by *Eucalyptus parramattensis* subsp. *parramattensis*, *Angophora bakeri* and *E. sclerophylla*. A small tree stratum of *Melaleuca decora* is sometimes present, generally in areas with poorer drainage. It has a well developed shrub stratum consisting of sclerophyllous species such as *Banksia spinulosa* subsp. *spinulosa*, *M. nodosa*, *Hakea sericea* and *H. dactyloides*. The ground stratum contains a diverse range of forbs including *Themeda australis*, *Entolasia stricta*, *Cyathochaeta diandra*, *Dianella revoluta* subsp. *revoluta*, *Stylidium graminifolium*, *Platysace ericoides*, *Laxmannia gracilis* and *Aristida warburgii*.

Castlereagh Scribbly Gum Woodland occurs almost exclusively on soils derived from Tertiary alluvium, with a small number of sample sites located on adjoining shale or Holocene alluvium where, presumably, the influence of Tertiary alluvium is strong. It is most often found on sandy soils and tends to occur on slightly higher ground (> 27 m) than Map Units 3 and 103, at least in the heart of the Castlereagh area. The Castlereagh Nature Reserve is an exception to this rule with Castlereagh Ironbark Forest occurring on an area of localised, elevated clay soil. Map Unit 6 grades into either Map Unit 3 or Map Unit 103 with decreasing distance from the Shale/Tertiary alluvium Boundary. The transition is unpredictable, but appears to be a function of the interaction of localised drainage conditions and the thickness of the Tertiary alluvium mantle. The main occurrence of Castlereagh Scribbly Gum Woodland is in the Castlereagh Area, with small patches occurring at Kemps Creek and Longneck Lagoon. This community is also present around Holsworthy, however the floristic composition in this area is closer to Map Unit 3 than at other localities.

Previous floristic classifications:

Castlereagh Scribbly Gum Woodland corresponds to the community of the same name described by Benson (1992), (Map Unit 14a), and NPWS (1997).

Habitat:

Parent Geology: Tertiary alluvium (90%), Holocene alluvium (5%), Wianamatta Shale (5%)

	Mean	(±sd)	Range
Elevation (m)	33.1	(10.7)	7–63
Slope (° above horizontal)	0.7	(0.7)	0–1.6
Annual Rainfall (mm)	812.4	(26.2)	781–917
Ruggedness (900m)	2.1	(0.9)	0–4
Maximum temperature, Jan. (°C)	28.8	(4.5)	27.1–29.0
Solar radiation, January	216.3	(0.7)	216–218

Structure:

Growth form	Frequency (%)	Mean height (m)	(±sd)	Mean foliage cover (%)	(±sd)
Tree	100	13.8	(3.1)	15.1	(8.9)
Small tree	40	8.4	(3.5)	7.5	(2.9)
Shrub	100	2.2	(0.9)	22.2	(11.6)
Forb	100	0.7	(0.5)	33.8	(30.1)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 24 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 39 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 24 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora bakeri	3	73	2	11	positive
Eucalyptus parramattensis subsp. *parramattensis*	2	77	1	1	positive
Eucalyptus sclerophylla	4	69	4	7	positive
Melaleuca decora	4	58	3	10	positive
Shrub stratum					
Acacia brownii	2	54	1	2	positive
Acacia elongata	2	46	2	2	positive
Banksia oblongifolia	2	35	2	4	positive
Banksia spinulosa var. *spinulosa*	3	81	2	23	positive
Bossiaea rhombifolia subsp. *rhombifolia*	2	23	3	2	positive
Callistemon pinifolius	1	38	2	1	positive
Cryptandra amara var. *amara*	2	23	2	2	positive
Daviesia squarrosa	2	42	1	1	positive
Daviesia ulicifolia	2	54	2	14	positive
Dillwynia tenuifolia	3	58	3	3	positive
Gompholobium pinnatum	2	27	–	0	positive
Grevillea mucronulata	2	73	2	14	positive
Hakea dactyloides	2	77	1	15	positive
Hakea sericea	3	81	2	20	positive
Isopogon anemonifolius	1	38	2	14	positive
Leptospermum polygalifolium subsp. *polygalifolium*	2	31	2	6	positive
Leptospermum trinervium	3	54	2	27	constant
Lissanthe strigosa	2	42	2	20	constant
Melaleuca erubescens	1	31	2	1	positive
Melaleuca nodosa	3	81	3	7	positive
Melaleuca thymifolia	2	35	1	1	positive
Micromyrtus ciliata	2	35	–	0	positive
Micromyrtus minutiflora	2	27	–	0	positive
Persoonia nutans	1	35	–	0	positive
Pimelea linifolia subsp. *linifolia*	2	85	2	26	positive
Pultenaea elliptica	2	54	2	7	positive
Ground stratum					
Aristida ramosa	2	50	2	19	positive
Aristida vagans	2	50	2	45	constant
Aristida warburgii	2	58	1	2	positive
Boronia polygalifolia	1	27	2	2	positive
Burchardia umbellata	2	31	1	1	positive
Cheilanthes sieberi subsp. *sieberi*	2	58	2	51	constant
Cyathochaeta diandra	3	88	2	20	positive
Dampiera stricta	1	35	2	9	positive
Dianella revoluta var. *revoluta*	2	77	2	36	positive
Entolasia stricta	3	96	3	57	positive
Eragrostis brownii	2	77	2	18	positive
Gonocarpus tetragynus	2	81	2	20	positive
Goodenia bellidifolia subsp. *bellidifolia*	3	35	2	5	positive
Goodenia paniculata	2	27	2	2	positive
Haemodorum planifolium	1	35	1	3	positive
Hypericum gramineum	2	54	2	18	positive
Laxmannia gracilis	2	50	1	17	positive
Lepyrodia scariosa	3	50	2	7	positive
Lomandra glauca	2	31	2	8	positive
Lomandra multiflora subsp. *multiflora*	2	81	2	49	positive
Microlaena stipoides var. *stipoides*	2	69	3	69	constant
Mitrasacme polymorpha	2	23	1	2	positive
Opercularia diphylla	2	73	2	34	positive
Panicum effusum	3	23	2	6	positive
Panicum simile	2	62	2	32	positive
Patersonia sericea	1	50	1	10	positive
Platysace ericoides	2	50	2	10	positive
Pomax umbellata	2	46	2	35	constant
Ptilothrix deusta	3	23	3	6	positive
Stylidium graminifolium	3	69	1	7	positive
Themeda australis	3	85	3	56	positive
Thysanotus tuberosus subsp. *tuberosus*	2	27	1	6	positive
Xanthorrhoea minor subsp. *minor*	2	77	1	2	positive
Climbers					
Cassytha glabella f. *glabella*	2	58	2	14	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Corymbia gummifera	1	12	2	30	uninform.
Eucalyptus beyeriana	4	4	–	0	uninform.
Eucalyptus eugenioides	3	4	2	12	uninform.
Eucalyptus fibrosa	2	27	4	16	uninform.
Eucalyptus longifolia	2	4	1	2	uninform.
Eucalyptus sideroxylon	3	15	–	0	uninform

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Ground stratum					
Hypochaeris radicata	2	45	1	31	constant

Map Unit 8:

Agnes Banks Woodland

Sample sites: (2)
Area (ha) 1750 / 1997 (± range): 627 / 98 (±8)
Proportion extant (± range): 15.6 (±1.3)%
No. taxa (total / unique): 56 / 1
No. taxa per plot (±sd): 33.0 (±4.2)

Map Unit 8 is a low woodland dominated By *Eucalyptus sclerophylla* and *Angophora bakeri* with a diverse understorey of sclerophyllous shrub species. These include *Banksia oblongifolia*, *B. aemula*, *Conospermum taxifolium*, *Leptospermum trinervium*, *Dillwynia sericea*, *Monotoca scoparia and Persoonia nutans*. The ground stratum includes *Lepidosperma urophorum*, *Platysace ericoides*, *Pimelea linifolia* subsp *linifolia*, *Mitrasacme polymorpha*, *Trachymene incisa* subsp. *incisa* and *Stylidium graminifolium*.

This community is restricted to small areas of sand dunes overlying Tertiary alluvium at Agnes Banks on the east bank of the Hawkesbury River. In low-lying, poorly drained areas Map Unit 8 grades into Map Unit 3. On higher ground where the aeolian sand deposits overlay sandy alluvial soils the transition is to Map Unit 6, to which Map Unit 8 is closely related.

Previous floristic classifications:

Castlereagh Swamp Woodland corresponds to the community of the same name described by Benson (1992).

Habitat:

Parent Geology: Aeolian Deposits (100%)

	Mean (±sd)	Range
Elevation (m)	30.5 (0.7)	30–31
Slope (° above horizontal)	0.6 (0.9)	0–1.3
Annual rainfall (mm)	803.0 (0.0)	0–803
Ruggedness (900m)	1.0 (0.0)	1–1
Maximum temperature, Jan. (°C)	29.1 (0.0)	29.1–29.1
Solar radiation, January	216.0 (0.0)	216–216

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	15.0 (0.0)	12.5 (3.5)
Small tree	50	8.0 (–)	20.0 (–)
Shrub	100	3.3 (2.5)	26.7 (5.8)
Forb	100	0.1 (0.0)	22.5 (24.7)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 19 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 28 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 19 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora bakeri	5	100	2	13	positive
Eucalyptus sclerophylla	4	100	4	9	positive
Shrub stratum					
Acacia brownii	1	50	1	4	constant
Acacia elongata	1	50	2	4	constant
Acacia ulicifolia	1	50	1	24	constant
Amperea xiphoclada	3	50	1	2	positive
Baeckea diosmifolia	2	50	2	1	positive
Banksia aemula	4	50	–	0	positive
Banksia oblongifolia	3	100	2	5	positive
Bossiaea heterophylla	1	50	2	8	constant
Bossiaea rhombifolia subsp. *rhombifolia*	3	50	2	3	positive
Brachyloma daphnoides	3	50	1	5	constant
Callistemon citrinus	1	50	–	0	positive
Callistemon linearis	2	50	1	2	positive
Conospermum taxifolium	3	100	–	0	positive
Dillwynia floribunda	1	50	2	2	positive
Dillwynia sericea	2	100	2	3	positive
Gompholobium huegelii	1	50	2	1	positive
Hibbertia fasciculata	2	50	–	0	positive
Isopogon anemonifolius	2	50	2	15	constant
Isopogon anethifolius	1	50	2	1	positive
Kunzea capitata	3	50	2	3	positive
Leptospermum polygalifolium subsp. *polygalifolium*	4	50	2	7	constant
Leptospermum trinervium	3	100	2	28	positive
Leucopogon virgatus	1	50	2	2	positive
Monotoca scoparia	3	100	1	15	positive
Olax stricta	2	50	1	1	positive
Persoonia linearis	1	50	2	32	constant
Persoonia nutans	2	100	1	1	positive
Petrophile pulchella	1	50	1	4	constant
Philotheca salsolifolia	3	50	3	1	positive
Pimelea linifolia subsp. *linifolia*	3	100	2	28	positive
Ricinocarpos pinifolius	3	50	1	3	positive
Ground stratum					
Caleana major	3	50	–	0	positive
Cyathochaeta diandra	4	50	2	23	constant
Dianella revoluta var. *revoluta*	2	50	2	37	constant
Haemodorum corymbosum	2	50	1	2	positive
Lepidosperma laterale	2	50	2	45	constant
Lepidosperma urophorum	3	100	2	1	positive
Leptocarpus tenax	4	50	–	0	positive
Lepyrodia scariosa	5	50	2	9	constant
Lomandra glauca	3	50	2	9	constant
Mitrasacme polymorpha	2	100	1	3	positive
Platysace ericoides	3	100	2	11	positive
Schizaea bifida	1	50	1	3	constant
Schoenus imberbis	2	50	1	2	positive
Stylidium graminifolium	3	100	2	9	positive
Themeda australis	1	50	3	57	constant
Trachymene incisa subsp. *incisa*	3	100	2	3	positive
Xanthorrhoea minor subsp. *minor*	2	50	2	5	constant
Climbers					
Cassytha glabella f. *glabella*	2	50	2	16	constant
Cassytha pubescens	1	50	2	19	constant

Map Unit 11:

Alluvial Woodland

Sample sites: (37)
Area (ha) 1750 / 1997 (± range): 36129 / 4698 (±903)
Proportion extant (± range): 13.0 (±2.5)%
No. taxa (total / unique): 256 / 11
No. taxa per plot (±sd): 37.5 (±11.7)

Alluvial Woodland is most often dominated by *Eucalyptus amplifolia* and *E. tereticornis* with *Angophora floribunda* occurring less frequently. Map Unit 11 often includes a stratum of small trees, frequently including *Acacia parramattensis* subsp. *parramattensis*, and less frequently *Casuarina glauca*, *Angophora floribunda* and *Melaleuca linariifolia*. A shrub stratum is usually evident, but is often sparse and invariably dominated by *Bursaria spinosa*. Map Unit 11 often has a dense ground cover dominated by grasses such as

Oplismenus aemulus, *Microlaena stipoides* var. *stipoides*, *Entolasia marginata* and *Echinopogon ovatus*. Herb species are also common, including *Solanum prinophyllum*, *Pratia purpurascens* and *Commelina cyanea*.

Map Unit 11 typically occurs in close proximity to minor watercourses draining soils derived from Wianamatta Shale. It is the most common community found on soils of recent alluvial deposition. Map Unit 11 is also found on the floodplains of the major watercourse, the Hawkesbury–Nepean River, but grades into Map Unit 12 on the terraces immediately adjacent to the river.

Previous floristic classifications:

River Flat Forest as described by Benson (1992), (Map Unit 9f), is herein divided into three separate communities: Map Units 11, 12 and 5. Map Units 11 and 12 correspond to the major groupings: Cumberland Plain Creek Systems and Hawkesbury–Nepean River and major Tributaries defined by NPWS (1997). Map Unit 5 was included as a component of the riverine vegetation by both Benson (1992) and NPWS (1997). Forest Red Gum–Cabbage Gum Forest, Forest Red Gum – Blue Gum Forest and Swamp Oak Forest (*sensu* NPWS 1997) are included in Map Unit 11. Camden White Gum Forest as described by Benson (1992), (Map Unit 6d), is included within Map Unit 12. Map Units 11, 12 and 5 fall within the definition of Sydney Coastal River Flat Forest listed under the *TSC Act* (1995).

Habitat:

Parent Geology: Holocene alluvium (59%), Wianamatta Shale (22%), Mittagong Formation (8%), Hawkesbury Sandstone (8%), Tertiary alluvium (3%)

	Mean	(±sd)	Range
Elevation (m)	78.6	(91.8)	3–303
Slope (° above horizontal)	2.2	(3.1)	0–13.5
Annual Rainfall (mm)	811.2	(45.5)	707–895
Ruggedness (900m)	6.6	(3.5)	2–18
Maximum Temperature, Jan. (°C)	28.3	(0.6)	27.1–29.1
Solar Radiation, January	215.5	(2.2)	210–219

Structure:

Growth form	Frequency (%)	Mean height (m)	(±sd)	Mean foliage cover (%)	(±sd)
Tree	100	23.7	(5.5)	23.2	(11.7)
Small tree	78	11.6	(4.2)	14.5	(8.5)
Shrub	92	3.7	(1.3)	12.9	(9.6)
Forb	95	0.5	(0.6)	60.9	(25.0)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 12 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 23 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 12 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acacia parramattensis	3	84	2	19	positive
Angophora floribunda	2	32	2	6	positive
Casuarina glauca	4	32	3	1	positive
Eucalyptus amplifolia	4	46	4	2	positive
Eucalyptus tereticornis	2	46	4	23	positive
Shrub stratum					
Acacia floribunda	3	32	1	6	positive
Bursaria spinosa	3	100	3	46	positive
Phyllanthus similis	3	30	2	1	positive
Sigesbeckia orientalis subsp. *orientalis*	2	49	2	7	positive
Ground stratum					
Adiantum aethiopicum	3	43	2	10	positive
Agrostis avenacea var. *avenacea*	1	24	1	7	positive
Brunoniella australis	3	54	3	33	constant
Centella asiatica	2	49	2	9	positive
Cheilanthes sieberi subsp. *sieberi*	2	51	2	52	constant
Commelina cyanea	3	59	2	10	positive
Desmodium varians	2	57	2	33	constant
Dichondra repens	3	97	3	45	positive
Echinopogon ovatus	3	84	2	29	positive
Einadia hastata	1	30	2	10	positive
Entolasia marginata	3	89	2	22	positive
Galium propinquum	2	35	2	9	positive
Juncus usitatus	2	35	1	8	positive
Lomandra longifolia	2	57	2	31	positive
Microlaena stipoides var. *stipoides*	4	97	3	67	positive
Oplismenus aemulus	3	95	2	15	positive
Oxalis perennans	3	57	2	26	positive
Plectranthus parviflorus	2	38	2	8	positive
Poranthera microphylla	2	41	2	22	constant
Pratia purpurascens	2	68	2	42	positive
Solanum prinophyllum	2	70	2	25	positive
Wahlenbergia gracilis	2	49	2	29	constant
Climbers					
Clematis glycinoides var. *glycinoides*	2	49	2	12	positive
Geitonoplesium cymosum	1	24	2	5	positive
Glycine clandestina	2	54	2	41	constant
Glycine tabacina	3	57	2	25	positive
Polymeria calycina	1	24	1	5	positive
Rubus parvifolius	2	35	2	5	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora subvelutina	4	14	4	2	uninform.
Corymbia maculata	4	3	4	4	uninform.
Eucalyptus baueriana	5	5	3	1	uninform.
Eucalyptus deanei	3	3	4	1	uninform.
Eucalyptus elata	1	3	–	0	uninform.
Eucalyptus eugenioides	1	19	2	11	uninform.
Eucalyptus globoidea	1	8	2	8	uninform.
Eucalyptus moluccana	1	14	4	20	uninform.
Eucalyptus piperita	1	3	2	7	uninform.
Eucalyptus punctata	1	8	3	25	uninform.
Eucalyptus sclerophylla	1	3	4	9	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Ligustrum sinense	1	46	1	13	positive
Olea europaea subsp. *africana*	2	41	2	26	constant
Ground stratum					
Anagallis arvensis	1	24	2	8	positive
Bidens pilosa	2	43	1	14	positive
Ciclospermum leptophyllum	2	27	1	9	positive
Cirsium vulgare	2	59	1	32	positive
Hypochaeris radicata	2	41	1	31	constant
Lantana camara	1	35	2	14	positive
Paspalum dilatatum	2	43	2	13	positive
Plantago lanceolata	2	46	2	24	constant
Senecio madagascariensis	2	57	2	51	constant
Setaria gracilis	2	46	2	25	constant
Sida rhombifolia	2	76	2	21	positive
Solanum chenopodioides	1	22	1	3	positive

Solanum pseudocapsicum	2	43	1	4	positive
Sonchus oleraceus	2	43	1	20	positive
Tradescantia fluminensis	3	32	4	3	positive
Climbers					
Araujia sericiflora	2	54	2	14	positive

Map Unit 5:

Riparian Woodland

Sample Sites: (2)
Area (ha) 1750 / 1997 (± range): Not calculated
Proportion Extant (± range): N/A
No. Taxa (total / unique): 45 / 11
No. Taxa per Plot (±sd): 23.5 (±2.1)

Map Unit 5 is a highly restricted community occurring within creeklines and adjacent swampy areas draining Wianamatta Shale soils. It is likely to be found in association with Map Unit 11, but is distinct from this community in occupying the wettest areas along watercourses. Although poorly sampled in this study, Map Unit 5 is likely to have an overstorey dominated by *Eucalyptus amplifolia* and *Casuarina glauca*. A shrub stratum is not usually present, but the ground stratum may be dense and include species such as *Alternanthera denticulata*, *Carex appressa*, *Persicaria decipiens* and *Juncus usitatus*.

Previous floristic classifications:

Riparian Woodland was included in a discussion on Riparian Habitats by NPWS (1997).

Habitat:

Parent Geology: Wianamatta Shale (50%), Holocene alluvium (50%)

	Mean	(±sd)	Range
Elevation (m)	34.0	(5.7)	30–38
Slope (° above horizontal)	1.3	(0.5)	0.9–1.7
Annual Rainfall (mm)	829.0	(0.0)	829–929
Ruggedness (900m)	3.5	(0.7)	3–4
Maximum Temperature, Jan. (°C)	27.9	(0.4)	27.6–28.2
Solar Radiation, January	217.0	(0.0)	217–217

Structure:

Growth form	Frequency (%)	Mean height (m)	(±sd)	Mean foliage cover (%)	(±sd)
Tree	100	26.0	(8.5)	27.5	(31.8)
Small Tree	50	10	(–)	15	(–)
Rushes	50	2	(–)	5	(–)
Forb	100	0.5	(0.7)	57.5	(3.5)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 14 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 21 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 14 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Casuarina glauca	6	50	3	3	positive
Eucalyptus amplifolia	4	50	4	4	constant
Melaleuca styphelioides	1	50	4	3	constant
Shrub stratum					
Bursaria spinosa	1	50	3	49	constant
Ground stratum					
Agrostis avenacea var. *avenacea*	3	100	1	8	positive
Alternanthera denticulata	4	100	1	2	positive
Azolla filiculoides var. *rubra*	2	50	–	0	positive
Brunoniella australis	1	50	3	34	constant
Cardamine paucijuga	1	50	1	1	positive
Carex appressa	3	100	2	2	positive
Centella asiatica	4	50	2	11	constant
Centipeda minima var. *minima*	3	50	2	1	positive
Commelina cyanea	2	50	2	13	constant
Cynodon dactylon	4	100	2	5	positive
Damasonium minus	4	100	–	0	positive
Echinopogon ovatus	2	50	2	32	constant
Eclipta platyglossa	2	50	2	1	positive
Elatine gratioloides	4	50	–	0	positive
Eleocharis cylindrostachys	1	50	–	0	positive
Eleocharis sphacelata	2	50	–	0	positive
Entolasia marginata	1	50	2	26	constant
Eriochloa pseudoacrotricha	1	50	1	2	positive
Isolepis inundata	1	50	2	1	positive
Juncus planifolius	4	50	2	1	positive
Juncus usitatus	3	100	1	10	positive
Lemna disperma	3	50	–	0	positive
Ludwigia peploides subsp. *montevidensis*	3	50	–	0	positive
Lythrum hyssopifolia	1	50	3	1	positive
Marsilea hirsuta	1	50	–	0	positive
Maundia triglochinoides	1	50	–	0	positive
Microlaena stipoides var. *stipoides*	2	50	3	69	constant
Myriophyllum simulans	2	50	–	0	positive
Paspalum distichum	3	50	–	0	positive
Persicaria decipiens	4	100	1	1	positive
Pratia purpurascens	3	50	2	44	constant
Ranunculus inundatus	2	50	–	0	positive
Triglochin microtuberosum	1	50	–	0	positive
Triglochin striatum	5	50	–	0	positive
Typha orientalis	3	50	–	0	positive
Climbers					
Glyceria australis	5	50	–	0	positive
Parsonsia straminea	1	50	1	4	constant

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Ligustrum sinense	1	50	1	15	constant
Olea europaea subsp. *africana*	2	50	2	27	constant
Shrub stratum					
Rubus sp.	1	50	1	5	constant
Sida rhombifolia	1	50	2	24	constant
Solanum pseudocapsicum	3	50	1	6	constant
Verbena bonariensis	3	50	1	5	constant
Ground stratum					
Anagallis arvensis	2	50	1	9	constant
Aster subulatus	1	100	1	3	positive
Bidens pilosa	2	50	1	16	constant
Bryophyllum delagoense	1	50	3	1	positive
Ciclospermum leptophyllum	1	50	1	10	constant
Cirsium vulgare	1	50	1	34	constant
Cotula coronopifolia	1	50	–	0	positive
Crassula sarmentosa var *sarmentosa*	1	50	–	0	positive
Cyperus eragrostis	4	100	2	2	positive
Leontodon taraxacoides subsp *taraxacoides*	3	50	2	11	constant
Paspalum dilatatum	2	50	2	15	constant
Plantago lanceolata	3	50	2	26	constant
Senecio madagascariensis	2	50	2	52	constant
Setaria gracilis	3	50	2	26	constant
Solanum nigrum	1	50	1	18	constant
Sonchus oleraceus	3	100	1	22	positive
Tradescantia fluminensis	3	50	3	5	constant

Climbers					
Aranjia sericiflora	2	50	2	17	constant
Myriophyllum aquaticum	2	50	–	0	positive
Myrsiphyllum asparagoides	3	50	2	22	constant

Map Unit 12:

Riparian Forest

Sample Sites: (9)
Area (ha) 1750 / 1997 (± range): 2989 / 717 (±137)
Proportion Extant (± range): 24.0 (±4.6)%
No. Taxa (total / unique): 113 / 5
No. Taxa per Plot (±sd): 30.9 (±7.6)

Riparian Forest is dominated by one or more of the following tree species: *Eucalyptus botryoides*, *E. elata* and *Angophora subvelutina*. A small tree stratum is usually present, and often contains species such as *Acacia binervia*, *A. floribunda* and *A. mearnsii*, although no particular species occurred consistently across the sample sites. Common species occurring in the ground stratum include *Oplismenus aemulus*, *Pteridium esculentum*, *Microlaena stipoides* var. *stipoides*, *Stipa ramosissima* and *Echinopogon ovatus*.

Map Unit 12 is not widely distributed and only occurred at sample sites on the banks of the Hawkesbury–Nepean River or on the terraces immediately adjacent to the river.

Previous floristic classifications:

Riparian Forest falls within Benson's (1992) River Flat Forest (Map Unit 9f), but includes Map Unit 6d, Camden White Gum Forest. This community falls within the definition of the Sydney Coastal River Flat Forest listed under the *TSC Act* (1995). The relationship between these communities is discussed in more detail in the description of Map Unit 11. Riparian Forest broadly corresponds with NPWS (1997) grouping Hawkesbury–Nepean River and Major Tributaries and includes the sub-units Blue Gum – River Peppermint – Blue Box Forest, Camden White Gum – River Peppermint Forest, Cabbage Gum – Broad-leaved Apple Forest, River-Oak Forest and possibly Swamp Mahogany Forest (NPWS 1997).

Habitat:

Parent Geology: Holocene alluvium (100%)

	Mean	(±sd)	Range
Elevation (m)	43.1	(26.3)	10–73
Slope (° above horizontal)	3.5	(4.0)	0–10.6
Annual Rainfall (mm)	769.2	(68.3)	708–861
Ruggedness (900m)	5.9	(3.9)	2–14
Maximum Temperature, Jan. (°C)	28.0	(0.4)	27.5–28.8
Solar Radiation, January	215.1	(1.8)	213–217

Structure:

Growth form	Frequency (%)	Mean height (m)	(±sd)	Mean foliage cover (%)	(±sd)
Tree	100	24.7	(5.9)	20.9	(11.5)
Small Tree	89	12.0	(3.3)	23.8	(15.5)
Shrub	100	4.0	(1.8)	14.6	(20.4)
Forb	100	1.0	(0.0)	46.3	(27.7)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 6 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 17 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 6 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acacia binervia	4	44	4	1	positive
Angophora subvelutina	4	44	4	2	positive
Backhousia myrtifolia	3	33	5	2	positive
Eucalyptus benthamii	3	22	–	0	positive
Eucalyptus botryoides	5	33	–	0	positive
Eucalyptus elata	4	33	–	0	positive
Stenocarpus salignus	1	22	1	1	positive
Shrub stratum					
Acacia floribunda	3	44	1	7	positive
Hymenanthera dentata	3	67	2	2	positive
Lomatia myricoides	2	33	2	1	positive
Phebalium squamulosum subsp. *squamulosum*	2	33	–	0	positive
Phyllanthus gunnii	3	44	2	2	positive
Sigesbeckia orientalis subsp. *orientalis*	3	44	2	8	positive
Austrostipa ramosissima	3	78	2	2	positive
Carex longebrachiata	2	22	2	2	positive
Cyperus enervis	3	22	2	1	positive
Dichelachne crinita	3	22	–	0	positive
Dichondra repens	3	78	3	47	constant
Echinopogon ovatus	2	67	2	32	constant
Entolasia marginata	2	44	2	26	constant
Gonocarpus longifolius	3	22	–	0	positive
Hydrocotyle laxiflora	2	22	2	2	positive
Lomandra longifolia	2	56	2	32	constant
Microlaena stipoides var. *stipoides*	4	100	3	69	positive
Oplismenus aemulus	3	89	2	18	positive
Oxalis perennans	3	44	2	27	constant
Pelargonium inodorum	1	22	–	0	positive
Poa affinis	3	44	2	7	positive
Poranthera microphylla	3	56	2	23	constant
Pratia purpurascens	3	56	2	43	constant
Pteridium esculentum	3	78	2	14	positive
Rumex brownii	1	33	1	4	positive
Veronica plebeia	3	56	2	22	constant
Wahlenbergia gracilis	2	56	2	29	constant
Climbers					
Glycine clandestina	2	56	2	42	constant

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora floribunda	1	22	2	7	uninform.
Eucalyptus baueriana	3	11	4	1	uninform.
Eucalyptus saligna × botryoides	5	11	–	0	uninform.
Eucalyptus tereticornis	2	11	4	25	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Celtis occidentalis	4	22	1	1	positive
Gleditsia triacanthos	2	33	–	0	positive
Ligustrum sinense	3	100	1	14	positive
Olea europaea subsp. *africana*	3	56	2	27	constant
Shrub stratum					
Sida rhombifolia	1	67	2	24	constant
Ground stratum					
Acetosella vulgaris	3	33	–	0	positive
Bidens pilosa	2	44	1	16	constant
Bromus catharticus	1	22	1	2	positive
Delairea odorata	3	33	–	0	positive
Ehrharta erecta	5	33	2	3	positive
Lonicera japonica	4	44	1	1	positive
Polycarpon tetraphyllum	2	22	1	1	positive

Senecio madagascariensis	3	44	2	52	constant
Setaria gracilis	1	78	2	25	positive
Tradescantia fluminensis	5	67	3	4	positive
Climbers					
Araujia sericiflora	2	56	2	17	constant
Cardiospermum grandiflorum	3	44	2	1	positive
Myrsiphyllum asparagoides	2	44	2	22	constant
Passiflora subpeltata	2	22	–	0	positive

Map Unit 9:

Shale Hills Woodland

Sample Sites: (61)
Area (ha) 1750 / 1997 (± range): 38274 / 4309 (±596)
Proportion Extant (± range): 11.3 (±1.5)%
No. Taxa (total / unique): 260 / 14
No. Taxa per Plot (±sd): 37.5 (±6.9)

Map Unit 9 is dominated by *Eucalyptus moluccana* and *E. tereticornis* with *E. crebra* occurring less frequently. A small tree stratum is often present and frequently includes *Acacia implexa* together with a variety of the commonly occurring *Eucalyptus* species. Map Unit 9 typically has a shrub stratum dominated by *Bursaria spinosa*, and more rarely includes other species such as *A. falcata*, *Breynia oblongifolia*, *Indigofera australis* and *Dodonaea viscosa* subsp. *cuneata*. The ground stratum is variable in cover. A dense cover of grass and herb species is typical, but this may become quite sparse under a dense shrub canopy of *B. spinosa* or the exotic species *Olea europaea* subsp. *africana*. Species include *Dichondra repens*, *Brunoniella australis*, *Aristida ramosa*, *Desmodium varians*, *Microlaena stipoides* var. *stipoides*, *Themeda australis* and *Cheilanthes sieberi* subsp. *sieberi*.

Shale Hills Woodland occurs almost exclusively on soils derived from Wianamatta Shale however three sample sites were located on soils that were clearly alluvial in nature. This result is difficult to explain and no attempt was made to model the distribution of Map Unit 9 on this geology. Map Unit 9 is closely related to Map Unit 10 but there is a reasonably clear differentiation between the habitats of the two communities. Map Unit 9 is largely confined to the southern half of the study area and occurs at higher elevations and on steeper slopes than Map Unit 10. It is most often found on undulating country with a relatively high degree of ruggedness and rarely north of Mulgoa Nature Reserve and Prospect Reservoir. Sample sites at these locations were sometimes difficult to distinguish from Map Unit 10. On very steep, sheltered hillsides Map Unit 9 grades into Map Unit 14.

Previous floristic classifications:

Cumberland Plains Woodland as described by Benson 1992 (Map Units 9b?, 10c and 10d) and as listed under the *TSC Act* (1995), is herein divided into two separate communities: Map Units 9 and 10. Map Unit 9 includes areas previously recognised as Map Units 9b, 10c and 10d (Benson 1992), but most often corresponds with Map Unit 10d in the southern half of the study area. Although Benson (1992) ascribed vegetation in the north of the study area to Map Unit 10d these areas are included in Map Unit 10 in this survey.

Habitat:

Parent Geology: Wianamatta Shale (92%), Holocene alluvium (8%)

	Mean (±sd)	Range
Elevation (m)	111.5 (68.8)	36–328
Slope (° above horizontal)	6.1 (5.3)	0–22.0
Annual Rainfall (mm)	811.6 (42.9)	722–903
Ruggedness (900m)	12.1 (7.5)	1–40
Maximum Temperature, Jan. (°C)	27.8 (5.9)	26.7–28.9
Solar Radiation, January	214.1 (3.3)	201–217

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	22.8 (6.1)	18.5 (9.4)
Small Tree	59	10.5 (4.2)	11.1 (11.4)
Shrub	95	3.8 (1.6)	19.6 (13.6)
Forb	100	0.5 (0.5)	43.9 (24.3)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 15 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 28 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 15 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acacia implexa	2	57	2	10	positive
Eucalyptus moluccana	4	70	4	15	positive
Eucalyptus tereticornis	4	70	4	20	positive
Shrub stratum					
Bursaria spinosa	4	92	3	45	positive
Dodonaea viscosa subsp. *cuneata*	1	11	2	2	positive
Phyllanthus virgatus	2	23	1	5	positive
Ground stratum					
Ajuga australis	2	25	1	4	positive
Aristida ramosa	3	84	2	15	positive
Arthropodium milleflorum	2	38	2	16	positive
Asperula conferta	2	61	2	6	positive
Austrodanthonia caespitosa	3	10	2	1	positive
Austrodanthonia racemosa var. *racemosa*	2	31	2	8	positive
Bothriochloa macra	1	28	1	2	positive
Brunoniella australis	3	85	3	29	positive
Carex inversa	2	62	2	6	positive
Cheilanthes distans	1	31	1	3	positive
Cheilanthes sieberi subsp. *sieberi*	2	69	2	50	constant
Chloris truncata	2	20	1	2	positive
Chloris ventricosa	3	41	2	4	positive
Crassula sieberiana	2	13	1	3	positive
Cyperus gracilis	2	48	2	7	positive
Desmodium brachypodum	2	46	1	6	positive
Desmodium varians	3	82	2	30	positive
Dichanthium sericeum	2	16	1	1	positive
Dichelachne micrantha	2	61	2	29	positive
Dichondra repens	3	97	3	43	positive
Echinopogon ovatus	2	48	2	31	constant
Einadia nutans	2	30	2	3	positive
Einadia polygonoides	3	13	2	1	positive
Einadia trigonos	2	23	2	5	positive
Elymus scaber var. *scaber*	1	20	1	1	positive
Eremophila debilis	2	31	2	5	positive
Eriochloa pseudoacrotricha	2	10	1	1	positive
Euchiton sphaericus	2	39	1	15	positive
Galium migrans	2	15	2	1	positive
Galium propinquum	2	23	2	9	positive
Geranium homeanum	2	15	2	3	positive
Geranium solanderi var. *solanderi*	1	15	1	2	positive
Hypericum gramineum	2	39	2	18	positive
Hypoxis hygrometrica	1	25	2	9	positive
Microlaena stipoides var. *stipoides*	3	79	3	68	constant
Oxalis perennans	2	52	2	25	positive

Panicum effusum	1	18	2	5	positive
Plectranthus parviflorus	2	26	2	8	positive
Poa labillardieri var. *labillardieri*	3	38	2	16	positive
Scleria mackaviensis	3	23	2	1	positive
Scutellaria humilis	2	13	2	2	positive
Senecio diaschides	1	13	1	1	positive
Senecio hispidulus var. *hispidulus*	2	15	2	4	positive
Sida corrugata	2	39	–	0	positive
Solanum prinophyllum	1	46	2	25	positive
Sorghum leiocladum	2	11	1	1	positive
Sporobolus creber	2	36	1	5	positive
Sporobolus elongatus	2	21	1	3	positive
Themeda australis	4	77	3	55	positive
Wahlenbergia gracilis	2	49	2	28	positive
Wahlenbergia stricta subsp. *stricta*	2	11	2	3	positive
Zornia dyctiocarpa var. *dyctiocarpa*	1	10	1	1	positive
Climbers					
Clematis glycinoides var. *glycinoides*	2	31	2	12	positive
Glycine microphylla	2	39	2	18	positive
Glycine tabacina	2	56	2	24	positive
Rubus parvifolius	2	18	2	6	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora floribunda	3	3	2	8	uninform.
Angophora subvelutina	3	2	4	3	uninform.
Corymbia maculata	5	3	4	4	uninform.
Eucalyptus amplifolia	4	5	4	4	uninform.
Eucalyptus crebra	4	31	3	17	uninform.
Eucalyptus eugenioides	3	13	2	11	uninform.
Eucalyptus fibrosa	1	2	4	18	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Olea europaea subsp. *africana*	3	84	2	20	positive
Shrub stratum					
Sida rhombifolia	2	54	2	21	positive
Ground stratum					
Centaurium tenuiflorum	2	28	1	9	positive
Ciclospermum leptophyllum	1	28	1	8	positive
Cirsium vulgare	2	70	1	29	positive
Paspalum dilatatum	2	36	2	12	positive
Plantago lanceolata	2	59	2	21	positive
Richardia stellaris	1	21	1	6	positive
Senecio madagascariensis	2	87	2	47	positive
Solanum nigrum	1	38	1	15	positive
Araujia sericiflora	2	52	2	13	positive

Map Unit 10:

Shale Plains Woodland

Sample Sites: (93)
Area (ha) 1750 / 1997 (± range): 87175 / 6745 (±968)
Proportion Extant (± range): 7.7 (±1.1)%
No. Taxa (total / unique): 301 / 14
No. Taxa per Plot (±sd): 42.5 (±9.1)

Shale Plains Woodland is dominated by *Eucalyptus moluccana* and *E. tereticornis* with *E. crebra*, *E. eugenioides* and *Corymbia maculata* occurring less frequently. These species often form a separate small tree stratum, occasionally including other species such as *Exocarpos cupressiformis*, *Acacia parramattensis* subsp. *parramattensis* and *Acacia decurrens*. A shrub stratum is usually present and dominated by *Bursaria spinosa*. Common ground stratum species include *Dichondra repens*, *Aristida vagans*, *Microlaena stipoides var stipoides*, *Themeda australis*, *Brunoniella australis*, *Desmodium varians*, *Opercularia diphylla*, *Wahlenbergia gracilis* and *Dichelachne micrantha*.

Shale Plains Woodland is the most widely distributed community on the Cumberland Plain. It predominantly occurs on soils derived from Wianamatta Shale, but also occurs on Holocene alluvium in well-drained areas. Isolated patches of Map Unit 10 may be found on soils derived from the Mittagong Formation, but only in the vicinity of outcrops of almost pure shale. Very rarely, it may occur on soils derived from Tertiary alluvium, but it is more usual for Map Unit 10 to grade into Map Unit 103 near the boundary of Shale and Tertiary alluvium. Towards the edge of the Cumberland Plain Map Unit 10 grades into Map Unit 1 as the depth of the shale soil decreases and the influence of the underlying sandstone increases. In the southern half of the study area Map Unit 10 grades into Map Unit 9 with increasing elevation and ruggedness. This gradation commences on the gentle rises running south from Prospect Reservoir in the centre of the plain, and south of Mulgoa Nature Reserve on the western boundary of the plain.

Previous floristic classifications:

Cumberland Plains Woodland as described by Benson (1992) (Map Units 9b, 10c and 10d) and as listed under the NSW Threatened Species Act (1995), is herein divided into two separate communities: Map Unit 9 and Map Unit 10. Map Unit 10 includes areas previously recognised as Map Units 9b, 10c and 10d (Benson 1992), but most often corresponds with Map Unit 10c. Although Benson (1992) ascribed vegetation in the north of the study area to Map Unit 10d these areas are included in Map Unit 10 in this survey.

Habitat:

Parent Geology: Wianamatta Shale (68%), Holocene alluvium (21%), Mittagong Formation (4%), Tertiary alluvium (3%), Hawkesbury Sandstone (3%), Aeolian Deposits (1%)

	Mean	**(±sd)**	**Range**
Elevation (m)	55.1	(34.0)	1–167
Slope (° above horizontal)	2.1	(2.5)	0–17.4
Annual Rainfall (mm)	829.0	(38.8)	739–923
Ruggedness (900m)	6.2	(3.5)	1–22
Maximum Temperature, Jan. (°C)	28.1	(0.6)	27.0–29.1
Solar Radiation, January	216.5	(2.0)	203–219

Structure:

Growth form	**Frequency (%)**	**Mean height (m) (±sd)**	**Mean foliage cover (%)(±sd)**
Tree	100	20.8 (5.1)	17.2 (9.3)
Small Tree	57	9.8 (3.5)	9.5 (7.3)
Shrub	100	3.1 (1.3)	14.0 (9.6)
Forb	99	0.5 (0.5)	45.1 (19.2)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 22 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 30 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 22 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Eucalyptus crebra	4	31	3	16	positive
Eucalyptus eugenioides	2	22	2	10	positive
Eucalyptus moluccana	4	69	4	12	positive
Eucalyptus tereticornis	4	67	3	18	positive

Exocarpos cupressiformis	1	24	1	11	positive
Shrub stratum					
Bossiaea prostrata	2	16	1	6	positive
Bursaria spinosa	4	97	3	42	positive
Daviesia ulicifolia	2	39	2	12	positive
Dillwynia sieberi	2	33	2	2	positive
Dodonaea viscosa subsp. *cuneata*	2	12	1	2	positive
Indigofera australis	2	17	2	6	positive
Phyllanthus virgatus	2	32	2	3	positive
Pultenaea microphylla	3	8	1	1	positive
Ground stratum					
Agrostis avenacea var. *avenacea*	1	23	1	6	positive
Ajuga australis	2	17	1	4	positive
Aristida ramosa	2	55	2	16	positive
Aristida vagans	3	91	2	38	positive
Arthropodium milleflorum	2	45	2	14	positive
Arthropodium minus	1	8	2	2	positive
Asperula conferta	2	32	2	7	positive
Austrodanthonia racemosa var. *racemosa*	2	30	2	7	positive
Austrodanthonia tenuior	2	43	2	12	positive
Bothriochloa decipiens	2	11	–	0	positive
Bothriochloa macra	1	15	1	3	positive
Brunoniella australis	3	88	3	26	positive
Centaurium spicatum	1	5	1	1	positive
Centella asiatica	2	20	2	10	positive
Cheilanthes sieberi subsp. *sieberi*	3	87	2	47	positive
Chloris ventricosa	2	18	2	5	positive
Chorizema parviflorum	1	8	2	2	positive
Chrysocephalum apiculatum	2	8	2	1	positive
Commelina cyanea	2	24	2	11	positive
Cymbonotus lawsonianus	1	8	1	1	positive
Cymbopogon refractus	2	47	2	13	positive
Daucus glochidiatus	2	9	2	1	positive
Desmodium varians	3	84	2	27	positive
Dianella longifolia	2	60	1	13	positive
Dichelachne micrantha	2	72	2	26	positive
Dichelachne parva	1	13	2	3	positive
Dichondra repens	3	98	3	40	positive
Dichopogon fimbriatus	1	5	1	1	positive
Dichopogon strictus	1	8	–	0	positive
Digitaria diffusa	1	5	1	1	positive
Echinopogon caespitosus var. *caespitosus*	2	46	2	23	positive
Einadia hastata	1	26	2	9	positive
Eragrostis leptostachya	2	68	2	17	positive
Eremophila debilis	2	35	2	3	positive
Eriochloa pseudoacrotricha	1	6	1	1	positive
Euchiton sphaericus	2	47	1	13	positive
Fimbristylis dichotoma	2	27	2	5	positive
Glossogyne tannensis	2	10	–	0	positive
Goodenia hederacea subsp. *hederacea*	2	48	2	31	positive
Hypericum gramineum	2	34	2	17	positive
Hypoxis hygrometrica	2	33	2	7	positive
Hypoxis pratensis var. *pratensis*	2	6	2	1	positive
Juncus usitatus	1	28	2	7	positive
Lomandra filiformis subsp. *filiformis*	3	65	2	30	positive
Lomandra multiflora subsp. *multiflora*	2	55	2	49	constant
Mentha diemenica	2	8	3	1	positive
Microlaena stipoides var. *stipoides*	4	92	3	66	positive
Opercularia diphylla	2	75	2	29	positive
Oxalis perennans	3	53	2	23	positive
Panicum effusum	2	19	2	5	positive
Paspalidium distans	3	74	2	19	positive
Plantago debilis	2	24	2	6	positive
Plantago gaudichaudii	2	6	1	1	positive
Pratia purpurascens	2	44	2	43	constant
Sporobolus creber	1	17	2	6	positive
Sporobolus elongatus	2	17	1	3	positive
Stackhousia viminea	1	47	1	7	positive
Themeda australis	4	89	3	52	positive
Tricoryne elatior	2	43	2	11	positive
Vernonia cinerea var. *cinerea*	2	46	2	14	positive
Veronica plebeia	2	39	2	20	positive
Wahlenbergia gracilis	2	71	2	24	positive
Wurmbea dioica subsp. *dioica*	2	11	2	1	positive
Zornia dyctiocarpa var. *dyctiocarpa*	1	6	1	1	positive
Climbers					
Glycine clandestina	2	49	2	41	constant
Glycine microphylla	2	37	2	17	positive
Glycine tabacina	2	67	2	20	positive
Hardenbergia violacea	2	45	1	29	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora bakeri	1	1	2	15	uninform.
Angophora floribunda	1	8	2	8	uninform.
Angophora subvelutina	4	5	4	2	uninform.
Corymbia maculata	4	5	4	3	uninform.
Eucalyptus amplifolia	4	5	4	4	uninform.
Eucalyptus baueriana	1	1	4	1	uninform.
Eucalyptus bosistoana	4	1	–	0	uninform.
Eucalyptus fibrosa	2	19	4	16	uninform.
Eucalyptus globoidea	1	1	2	9	uninform.
Eucalyptus longifolia	1	2	1	2	uninform.
Eucalyptus paniculata	4	2	2	3	uninform.
Eucalyptus punctata	3	4	3	27	uninform.
Syncarpia glomulifera	1	1	3	23	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Shrub stratum					
Sida rhombifolia	2	42	2	22	positive
Ground stratum					
Anagallis arvensis	2	20	1	7	positive
Bidens pilosa	2	31	1	14	positive
Centaurium tenuiflorum	2	27	1	8	positive
Cirsium vulgare	1	57	1	30	positive
Hypochaeris radicata	2	51	1	29	positive
Leontodon taraxacoides subsp. *taraxacoides*	2	28	2	8	positive
Plantago lanceolata	2	47	2	22	positive
Richardia stellaris	1	27	1	5	positive
Senecio madagascariensis	2	91	2	45	positive
Setaria gracilis	2	55	2	21	positive
Solanum nigrum	1	31	1	16	positive
Sonchus oleraceus	1	42	1	19	positive
Climbers					
Myrsiphyllum asparagoides	2	36	2	20	positive

Map Unit 13:

Western Sydney Dry Rainforest

Sample Sites: (13)
Area (ha) 1750 / 1997 (± range): 1282 / 338 (±35)
Proportion Extant (± range): 26.4 (±2.7)%
No. Taxa (total / unique): 185 / 23
No. Taxa per Plot (±sd): 42.4 (±12.8)

Western Sydney Dry Rainforest is typically dominated by a mixture of tree species including *Melaleuca styphelioides, Acacia implexa, Alectryon subcinereus* and, less frequently, *Streblus brunonianus*. Mesic species are predominant in the shrub stratum, such as *Pittasparum revalutum*, *Breynia oblangifolia*, *Cleradendrum tomentosum*, *Notelaea langifolia f. longifolia* and *Sigesbeckia orientalis* subsp. *orientalis*. The ground stratum consists primarily of a mixture of fern and herb species with relatively few grass species present. Frequently recorded species include *Adiantum aethiapicum*, *Pellaea falcata* var. *falcata*, *Asplenium flabellifolium*, *Dichondra repens*, *Microlaena stipoides* var. *stipaides*, *Oplismenus imbecillis*, *Plectranthus parvifolius*, *Desmadium varians*, *Galium propinquum* and *Stellaria flaccida*. Vine species are also common, including *Cayratia clematidea*, *Eustrephus latifalius*, *Geitonaplesium cymasum*, *Pandorea pandorana*, *Aphanapetalum resinosum* and *Stephania japonica* var. *discolar*.

Map Unit 13 is highly restricted in distribution. It occurs almost exclusively on soils derived from Wianamatta Shale and generally occupies sheltered lower slopes and gullies on steeply sloping, rugged topography. It is often found at higher elevations in areas receiving higher rainfall than Map Units 9 and 10. The transition from Map Unit 13 to Map Units 9 or 10 is often abrupt, and is likely to relate primarily to moisture availability and possibly fire history.

Previous floristic classifications:

Western Sydney Dry Rainforest is equivalent to Benson and Howell's (1994b) Map Unit 8d: Rainforest (Vine Thicket Rainforest). NPWS (1997) recognised this community under the name Dry Rainforest and considered it to be a variant of Floyd's (1990) Alliance VI, Sub-alliance 23 (*Ficus* spp. – *Streblus* – *Dendrocnide* – *Cassine*)). Western Sydney Dry Rainforest is listed as an Endangered Ecological Community under the *TSC Act* (1995).

Habitat:

Parent Geology: Wianamatta Shale (89%), Mittagong Formation (11%)

	Mean	(±sd)	Range
Elevation (m)	200.8	(81.9)	10–275
Slope (° above horizontal)	15.9	(6.4)	8.5–29.6
Annual Rainfall (mm)	868	(41.2)	809–918
Ruggedness (900m)	21.6	(7.5)	7–34
Maximum Temperature, Jan. (°C)	27.4	(0.6)	26.6–28.6
Solar Radiation, January	206.2	(6.4)	196–215

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	20.9 (10.3)	35.1 (22.3)
Small Tree	67	10.3 (4.9)	22.5 (14.7)
Shrub	78	3.3 (1.0)	26.4 (19.7)
Forb	67	0.2 (0.4)	45.0 (25.9)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 18 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 28 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 18 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acacia implexa	2	54	2	13	positive
Alectryon subcinereus	2	62	–	0	positive
Brachychiton papulneus	4	23	1	2	positive
Corymbia maculata	3	23	4	3	positive
Melaleuca styphelioides	4	77	2	2	positive
Melicope micrococca	1	38	–	0	positive
Streblus brunonianus	3	23	–	0	positive
Shrub stratum					
Abutilon oxycarpum	2	23	–	0	positive
Breynia ablangifolia	2	85	2	19	positive
Citriobatus pauciflorus	3	23	–	0	positive
Cleradendrum tomentasum	2	62	1	7	positive
Deeringia amaranthoides	2	31	–	0	positive
Hymenanthera dentata	2	54	2	2	positive
Natelaea longifolia f. *longifolia*	2	77	1	16	positive
Pittasporum revolutum	2	92	2	8	positive
Rapanea variabilis	2	46	2	7	positive
Sigesbeckia orientalis subsp. *orientalis*	2	62	2	8	positive
Salanum stelligerum	2	38	–	0	positive
Ground stratum					
Adiantum aethiopicum	4	100	2	10	positive
Asplenium flabellifalium	2	62	2	2	positive
Carex longebrachiata	1	23	2	1	positive
Cyperus enervis	1	23	2	1	positive
Cyperus imbecillis	2	31	2	1	positive
Desmodium varians	2	54	2	34	constant
Dichondra repens	3	69	3	47	constant
Doodia aspera	3	31	2	3	positive
Echinopogon ovatus	2	46	2	32	constant
Galium propinquum	2	46	2	9	positive
Geranium homeanum	3	46	2	4	positive
Microlaena stipoides var. *stipoides*	2	69	3	69	constant
Oplismenus imbecillis	3	77	2	9	positive
Pellaea falcata	3	85	2	3	positive
Plectranthus parviflarus	2	62	2	8	positive
Pseuderanthemum variabile	2	69	2	11	positive
Pyrrasia rupestris	2	23	–	0	positive
Stellaria flaccida	3	54	2	2	positive
Urtica incisa	1	38	–	0	positive
Climbers					
Aphanopetalum resinosum	3	62	–	0	positive
Cayratia clematidea	3	92	2	6	positive
Celastrus australis	2	31	2	1	positive
Cissus antarctica	3	46	2	1	positive
Eustrephus latifolius	2	85	2	8	positive
Geitonoplesium cymasum	2	92	1	5	positive
Marsdenia flavescens	3	31	–	0	positive
Marsdenia rostrata	3	31	2	1	positive
Pandarea pandorana	2	85	2	13	positive
Ripogonum album	1	23	–	0	positive
Rubus parvifolius	2	46	2	6	positive
Sarcopetalum harveyanum	2	23	1	2	positive
Stephania japonica var. *discolor*	2	54	2	2	positive
Tylophora barbata	3	31	2	6	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophara floribunda	1	8	2	8	uninform.
Eucalyptus moluccana	4	8	4	20	uninform.
Eucalyptus pilularis	4	8	4	13	uninform.
Eucalyptus tereticarnis	4	38	4	24	uninform.
Syncarpia glomulifera	1	8	3	20	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Olea europaea subsp. *africana*	3	89	2	26	positive
Shrub stratum					
Lantana camara	3	89	1	15	positive
Phytolacca octandra	3	22	1	2	positive
Solanum pseudocapsicum	2	44	1	6	positive
Ground stratum					
Cirsium vulgare	1	44	1	34	constant
Solanum nigrum	2	44	1	18	constant

Map Unit 14:

Moist Shale Woodland

Sample Sites: (10)
Area (ha) 1750 / 1997 (± range): 2034 / 604 (±65)
Proportion Extant (± range): 29.7 (±3.2)%
No. Taxa (total / unique): 124 / 5
No. Taxa per Plot (±sd): 35.9 (±8.4)

Moist Shale Woodland is dominated by *Eucalyptus tereticornis* and *E. moluccana* with *E. crebra* and *Corymbia maculata* occurring less frequently. These species may also comprise a small tree stratum together with *Acacia implexa* or *Acacia parramattensis* subsp. *parramattensis*. A relatively sparse shrub stratum is usually present and dominated by mesomorphic species. *Breynia oblongifolia*, *Clerodendrum tomentosum*, *Sigesbeckia orientalis* subsp. *orientalis*, *Bursaria spinosa and Olearia viscidula* are commonly occurring shrub species. The ground stratum is variable in cover and contains species such as *Desmodium varians*, *Cyperus gracilis*, *Galium propinquum*, *Cayratia clematidea*, *Glycine clandestina*, *Brunoniella australis*, *Desmodium brachypodum*, *Dichondra repens*, *Microlaena stipoides* var. *stipoides* and *Solanum prinophyllum*.

Moist Shale Woodland occurs exclusively on soils derived from Wianamatta Shale and is restricted to rugged areas at higher elevations in the southern half of the study area. This community appears to represent the endpoint of the gradient in elevation, rainfall and ruggedness from the central Cumberland Plain to the Razorback range at Picton. This gradient is parallelled by a transition from Map Unit 10 through Map Unit 9 with Map Unit 14 occurring on the upper portion of very steep sheltered slopes. Map Unit 14 is found in very similar environments to Map Unit 13 and since both communities are highly restricted, and were sampled at relatively few sites it is difficult to determine what factors are responsible for their relative distributions. Map Unit 14 tends to occupy upper slopes while Map Unit 13 is often found on lower slopes and in gullies, which presumably provide a more reliably moist environment for the constituent rainforest species. It is possible that Map Unit 14 represents a stage in the recovery of Map Unit 13 from fire.

Previous floristic classifications:

None known.

Habitat:

Parent Geology: Wianamatta Shale (100%)

	Mean	(±sd)	Range
Elevation (m)	221.8	(85.5)	61–304
Slope (° above horizontal)	12.4	(8.3)	3.3–24.9
Annual Rainfall (mm)	862.2	(33.6)	803–899
Ruggedness (900m)	27.9	(10.2)	13–39
Maximum Temperature, Jan. (°C)	27.3	(0.7)	26.5–28.8
Solar Radiation, January	207.4	(7.0)	193–215

Structure:

Growth form	Frequency (%)	Mean height (m)	(±sd)	Mean foliage cover (%)	(±sd)
Tree	100	24.7	(4.6)	18.9	(7.8)
Small Tree	89	10.8	(4.7)	18.1	(15.3)
Shrub	78	3.3	(1.0)	15.1	(15.1)
Forb	100	0.3	(0.5)	30.3	(25.0)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 12 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 26 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 12 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acacia implexa	3	40	2	13	constant
Brachychiton populneus	2	50	1	2	positive
Eucalyptus moluccana	4	60	4	19	positive
Eucalyptus tereticornis	4	60	4	24	constant
Shrub stratum					
Breynia oblongifolia	2	80	2	19	positive
Bursaria spinosa	2	70	3	48	constant
Clerodendrum tomentosum	2	70	1	7	positive
Myoporum montanum	1	60	–	0	positive
Olearia viscidula	2	50	1	3	positive
Sigesbeckia orientalis subsp. *orientalis*	2	70	2	8	positive
Ground stratum					
Adiantum aethiopicum	4	40	3	12	constant
Arthropodium milleflorum	2	50	2	18	constant
Asplenium flabellifolium	2	30	2	3	positive
Brunoniella australis	3	60	3	33	constant
Carex inversa	2	50	2	10	positive
Cheilanthes distans	2	40	1	5	positive
Chloris truncata	2	30	2	3	positive
Commelina cyanea	2	40	2	13	constant
Crassula sieberiana	2	30	1	3	positive
Cyperus gracilis	2	70	2	9	positive
Cyperus imbecillis	3	20	2	1	positive
Desmodium brachypodum	2	70	1	9	positive
Desmodium varians	2	100	2	33	positive
Dichondra repens	3	100	3	47	positive
Echinopogon ovatus	2	50	2	32	constant
Einadia hastata	2	50	2	11	positive
Einadia nutans	3	30	2	5	positive
Einadia polygonoides	2	30	3	2	positive
Galium propinquum	2	70	2	9	positive
Geranium homeanum	1	30	2	4	positive
Microlaena stipoides var. *stipoides*	1	70	3	69	constant
Notodanthonia longifolia	3	20	2	2	positive
Nyssanthes diffusa	2	60	–	0	positive
Oplismenus aemulus	3	40	2	19	constant
Oxalis perennans	2	50	2	27	constant
Paspalidium criniforme	2	20	2	2	positive
Pellaea falcata	2	40	2	4	positive
Plantago debilis	1	60	2	8	positive
Plectranthus parviflorus	2	60	2	9	positive
Poa sieberiana var. *sieberiana*	4	40	2	4	positive
Rumex brownii	2	50	1	4	positive
Scaevola albida var. *albida*	3	20	2	1	positive
Senecio quadridentatus	2	50	1	2	positive
Solanum prinophyllum	2	60	2	26	constant
Wahlenbergia gracilis	2	50	2	30	constant
Climbers					
Aphanopetalum resinosum	1	20	3	1	positive
Cayratia clematidea	2	80	2	6	positive
Celastrus australis	2	30	2	1	positive
Cissus antarctica	3	20	3	2	positive
Clematis glycinoides var. *glycinoides*	2	40	2	13	constant
Glycine clandestina	3	80	2	41	constant
Pandorea pandorana	2	40	2	14	constant

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Corymbia maculata	4	20	4	3	uninform.
Eucalyptus crebra	5	30	3	18	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Olea europaea subsp. *africana*	3	89	2	26	positive
Shrub stratum					
Lantana camara	2	44	1	15	constant
Opuntia aurantiaca	2	22	–	0	positive
Opuntia stricta	1	33	1	3	positive
Ground stratum					
Cirsium vulgare	2	67	1	33	constant
Lepidium africanum	1	33	1	2	positive
Plantago lanceolata	1	44	2	26	constant
Senecio madagascariensis	3	56	2	52	constant
Climbers					
Araujia sericiflora	1	56	2	17	constant

Map Unit 15:

Turpentine Ironbark Forest

Sample Sites: (22)
Area (ha) 1750 / 1997 (± range): 17354 / 236 (±49)
Proportion Extant (± range): 1.4 (±0.3)%
No. Taxa (total / unique): 208 / 14
No. Taxa per Plot (±sd): 42.6 (±9.0)

Turpentine Ironbark Forest is dominated by *Syncarpia glomulifera* with *E. paniculata* and *E. eugenioides* occurring less frequently. In areas of higher rainfall (1050–1080 mm *per annum*), *E. saligna* is dominant. *Eucalyptus punctata* occurs occasionally in areas where the shale soils form a relatively shallow mantle over the underlying sandstone. A stratum of small trees is usually present and is composed of a mixture of species including *Syncarpia glomulifera*, *Pittosporum undulatum*, *Trema aspera* and *Acacia parramattensis* subsp. *parramattensis*. The shrub stratum is usually sparse, and contains predominantly mesic species such as *Pittosporum revolutum*, *Breynia oblongifolia*, *Maytenus sylvestris*, *Polyscias sambucifolia* subsp. A, *Notelaea longifolia* f. *longifolia* and *Ozothamnus diosmifolius*. The ground stratum consists of a dense mixture of herb and grass species dominated by *Oplismenus aemulus*, *Pseuderanthemum variabile* and *Echinopogon ovatus*. Other frequently recorded species include *Entolasia marginata*, *Pratia purpurascens*, *Dianella longifolia*, *Arthropodium milleflorum* and *Rubus parvifolia*.

Turpentine Ironbark Forest occurs on soils derived from Wianamatta Shale and is restricted to the eastern edge of the Cumberland Plain where the average annual rainfall exceeds approximately 950 mm. Ascending to the Hornsby Plateau, Turpentine Ironbark Forest grades into Map Unit 152 as rainfall exceeds 1050 mm. This transition occurs at an altitude of approximately 100 m above sea level although Turpentine Ironbark Forest is found at altitudes of up to 200 m on the Western edge of the Hornsby Plateau where rainfall falls below 1050 mm. Close to the shale/sandstone boundary the community grades into Map Unit 43.

Turpentine Ironbark forest has been almost entirely cleared and has been listed under the *TSC Act* (1995) as Sydney Turpentine Ironbark Forest. Both Map Units 15 and 43 are considered to fall within this definition. Scattered remnants are located between Bankstown and Eastwood. Remnants at Denistone Park and Darvall Park (Eastwood), and Mobbs Hill (Carlingford) are at the upper limit of the rainfall range for this community. These remnants have previously been described as Blue Gum High Forest (Benson and Howell 1994a, NPWS 1997), but despite the dominance of *E. saligna* are floristically more similar to vegetation of the lower rainfall zone.

Previous floristic classifications:

Map Units 15 and 43 combined are equivalent to Turpentine Ironbark Forest as described by Benson and Howell (1994a), and listed under the *TSC Act* (1995) as Sydney Turpentine–Ironbark Forest.

Habitat:

Parent Geology: Wianamatta Shale (67%), Holocene alluvium (17%), Mittagong Formation (17%)

	Mean (±sd)	Range
Elevation (m)	69.8 (60.9)	9–184
Slope (° above horizontal)	3.9 (4.6)	0.4–12.8
Annual Rainfall (mm)	1018.0 (68.7)	886–1080
Ruggedness (900m)	12.8 (7.4)	4–21
Maximum Temperature, Jan. (°C)	26.9 (0.1)	26.8–27.0
Solar Radiation, January	216.7 (2.9)	211–219

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	23.3 (6.8)	35.8 (19.6)
Small Tree	83	9.6 (1.7)	29.4 (18.1)
Shrub	83	2.6 (0.9)	14.4 (20.1)
Forb	100	0.7 (0.5)	70.8 (31.1)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 18 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 33 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 18 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acacia parramattensis	2	59	2	21	positive
Elaeocarpus reticulatus	1	36	1	8	positive
Eucalyptus acmenoides	1	23	–	0	positive
Eucalyptus paniculata	3	45	2	2	positive
Eucalyptus pilularis	3	36	4	12	positive
Eucalyptus saligna	3	50	3	1	positive
Pittosporum undulatum	3	86	2	13	positive
Syncarpia glomulifera	4	77	3	18	positive
Shrub stratum					
Acacia floribunda	1	41	2	6	positive
Breynia oblongifolia	2	64	2	18	positive
Clerodendrum tomentosum	1	36	1	7	positive
Maytenus silvestris	1	55	2	3	positive
Notelaea longifolia f. *longifolia*	2	50	1	16	positive
Ozothamnus diosmifolius	2	59	1	27	positive
Pittosporum revolutum	2	73	2	8	positive
Polyscias sambucifolia subsp. *A*	2	68	2	10	positive
Rapanea variabilis	2	45	2	7	positive
Sigesbeckia orientalis subsp. *orientalis*	2	36	2	8	positive
Trema tomentosa var. *viridis*	3	36	1	2	positive
Ground stratum					
Adiantum aethiopicum	2	55	3	11	positive
Desmodium varians	1	41	2	34	constant
Dianella caerulea	2	73	2	27	positive
Dichondra repens	2	77	3	47	positive
Doodia aspera	2	36	2	2	positive
Echinopogon ovatus	2	55	2	31	constant
Entolasia marginata	2	82	2	24	positive
Entolasia stricta	2	45	3	59	constant
Geranium solanderi var. *solanderi*	1	23	1	3	positive
Lomandra longifolia	2	68	2	31	positive
Microlaena stipoides var. *stipoides*	3	95	3	68	positive
Oplismenus aemulus	2	82	2	17	positive

Oplismenus imbecillis	2	41	2	9	positive
Poa affinis	3	68	2	6	positive
Pratia purpurascens	2	64	2	43	constant
Pseuderanthemum variabile	3	91	2	9	positive
Rumex brownii	1	23	1	4	positive
Solanum prinophyllum	1	59	2	26	positive
Climbers					
Cayratia clematidea	3	45	2	6	positive
Clematis aristata	1	32	2	5	positive
Clematis glycinoides var. *glycinoides*	2	59	2	12	positive
Eustrephus latifolius	2	86	2	7	positive
Glycine clandestina	1	41	2	42	constant
Pandorea pandorana	2	86	2	12	positive
Passiflora herbertiana subsp. *herbertiana*	2	41	1	3	positive
Rubus parvifolius	2	41	2	6	positive
Sarcopetalum harveyanum	1	32	2	1	positive
Smilax australis	1	23	2	3	positive
Tylophora barbata	2	55	2	5	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora costata	1	23	2	19	uninform.
Angophora floribunda	5	9	2	8	uninform.
Eucalyptus deanei	4	5	4	1	uninform.
Eucalyptus eugenioides	4	5	2	12	uninform.
Eucalyptus globoidea	3	9	2	8	uninform.
Eucalyptus moluccana	1	5	4	20	uninform.
Eucalyptus punctata	1	32	3	24	uninform.
Eucalyptus resinifera	1	5	1	4	uninform.
Eucalyptus tereticornis	1	5	4	25	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Ligustrum lucidum	1	50	2	7	positive
Ligustrum sinense	1	83	1	15	positive
Shrub stratum					
Lantana camara	2	67	1	15	positive
Ochna serrulata	1	83	1	4	positive
Phytolacca octandra	1	33	1	2	positive
Sida rhombifolia	1	83	2	24	positive
Ground stratum					
Cirsium vulgare	1	50	1	34	constant
Conyza albida	1	50	2	9	positive
Ehrharta erecta	3	50	2	3	positive
Paspalum dilatatum	2	67	2	14	positive
Plantago lanceolata	1	50	2	26	constant
Protasparagus aethiopicus	2	50	1	8	positive
Rubus sp.	1	50	1	4	positive
Setaria gracilis	1	50	2	26	constant
Solanum nigrum	1	50	1	18	constant
Climbers					
Araujia sericiflora	1	50	2	17	constant
Hedera helix	1	33	–	0	positive

Map Unit 43:

Turpentine Ironbark Margin Forest

Sample Sites: (37)
Area (ha) 1750 / 1997 (± range): 12985 / 947 (±178)
Proportion Extant (± range): 7.3 (±1.4)%
No. Taxa (total / unique): 312 / 12
No. Taxa per Plot (±sd): 47.7 (±7.7)

Turpentine Ironbark Margin Forest is dominated by *Eucalyptus punctata* and *Syncarpia glomulifera* with a sparse stratum of small trees including *Acacia parramattensis* and *Pittosporum undulatum*. A variety of tree species occur more sporadically, including *Corymbia gummifera* and *E. globoidea*. The shrub stratum is usually relatively sparse and features mesic species such as *Polyscias sambucifolia* subsp. A, *Breynia oblongifolia* and *Notelaea longifolia f. longifolia*, as well as some sclerophyllous species such as *Leucopogon juniperinus*. The ground stratum is frequently dense and dominated by a range of grass species including *Entolasia marginata*, *E. stricta*, *Panicum simile*, *Themeda australis*, *Microlaena stipoides* var. *stipoides*, *Echinopogon caespitosus* var. *caespitosus* and *Oplismenus aemulus*. A variety of herb species are also represented. Frequently recorded species include *Pratia purpurascens*, *Gonocarpus tetragynus*, *Dianella caerulea*, *Dichondra repens* and *Pseuderanthemum variabile*.

Map Unit 43 occurs in higher rainfall areas on the margins of the Cumberland Plain in close proximity to the sandstone/shale boundary. Sample sites representative of this Map Unit were located on the south-western edge of the Hornsby Plateau, the northern end of the Woronora Plateau and west of Kurrajong. The majority of sample sites were located within 600 m of the shale/sandstone boundary. Soils typically had a relatively high level of sandstone influence. Areas with a lower level of sandstone influence have been extensively cleared and were not sampled in this survey. Where rainfall exceeds 1050 mm *per annum*, Map Unit 43 grades into Map Unit 152 as the level of sandstone influence in the soil decreases. In areas with lower rainfall Map Unit 43 grades into Map Unit 15.

Previous floristic classifications:

Map Units 15 and 43 combined are equivalent to Turpentine Ironbark Forest as described by Benson and Howell (1994a), and listed under the *TSC Act* (1995) as Sydney Turpentine-Ironbark Forest.

Habitat:

Parent Geology: Wianamatta Shale (75%), Mittagong Formation (17%), Hawkesbury Sandstone (8%)

	Mean	(±sd)	Range
Elevation (m)	116.8	(101.8)	2–308
Slope (° above horizontal)	7.6	(5.8)	0–18.0
Annual Rainfall (mm)	1009.3	(113.9)	825–1155
Ruggedness (900m)	15.2	(13.5)	2–43
Maximum Temperature, Jan. (°C)	27.6	(1.1)	26.0–29.1
Solar Radiation, January	213.1	(4.9)	205 – 219
Distance to Sandstone (m)	265.6	(296.9)	0 – 843.4

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	21.8 (5.0)	24.2 (10.8)
Small Tree	100	10.3 (3.6)	7.2 (4.7)
Shrub	100	2.6 (1.6)	11.0 (9.7)
Forb	100	0.8 (0.6)	51.3 (23.7)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 11 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 38 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 11 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acacia parramattensis	2	43	2	21	positive
Allocasuarina torulosa	2	46	2	10	positive
Angophora costata	2	54	2	17	positive
Eucalyptus globoidea	2	41	3	6	positive

Eucalyptus resinifera	2	32	1	3	positive
Pittosporum undulatum	2	84	2	12	positive
Syncarpia glomulifera	3	76	3	17	positive
Shrub stratum					
Acacia longifolia	2	32	1	7	positive
Bursaria spinosa	2	51	3	48	constant
Dodonaea triquetra	4	38	2	13	positive
Hibbertia aspera	2	51	2	16	positive
Leucopogon juniperinus	2	49	2	17	positive
Notelaea longifolia f. *longifolia*	1	41	1	16	positive
Ozothamnus diosmifolius	1	51	2	27	positive
Pittosporum revolutum	2	32	2	9	positive
Polyscias sambucifolia subsp. *A*	2	49	2	9	positive
Ground stratum					
Aristida vagans	3	49	2	45	constant
Austrostipa rudis	3	22	2	5	positive
Billardiera scandens	2	62	1	36	positive
Cheilanthes sieberi subsp. *sieberi*	2	54	2	52	constant
Dianella caerulea	2	78	2	26	positive
Dianella revoluta var. *revoluta*	1	43	2	37	constant
Dichondra repens	2	57	3	47	constant
Echinopogon ovatus	2	51	2	31	constant
Entolasia marginata	2	54	2	24	positive
Entolasia stricta	2	78	3	58	constant
Gonocarpus tetragynus	2	49	2	21	positive
Goodenia hederacea subsp. *hederacea*	2	49	2	33	constant
Imperata cylindrica var. *major*	3	54	2	11	positive
Lepidosperma laterale	2	62	2	44	constant
Lomandra longifolia	2	70	2	30	positive
Lomandra multiflora subsp. *multiflora*	1	57	2	50	constant
Microlaena stipoides var. *stipoides*	4	86	3	68	constant
Opercularia hispida	2	24	2	2	positive
Opercularia varia	1	22	2	2	positive
Oplismenus imbecillis	2	38	2	9	positive
Oxalis exilis	2	41	1	5	positive
Panicum simile	1	49	2	33	constant
Poa affinis	3	27	2	7	positive
Poa sieberiana var. *sieberiana*	1	22	2	3	positive
Pomax umbellata	1	43	2	35	constant
Pratia purpurascens	2	76	2	42	positive
Pseuderanthemum variabile	3	46	2	10	positive
Themeda australis	3	84	3	55	positive
Climbers					
Eustrephus latifolius	2	32	2	8	positive
Glycine clandestina	3	78	2	40	positive
Hardenbergia violacea	1	49	1	30	constant
Kennedia rubicunda	2	22	1	6	positive
Pandorea pandorana	2	51	2	12	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora floribunda	4	14	2	7	uninform.
Corymbia eximia	3	5	2	3	uninform.
Corymbia gummifera	3	27	2	29	uninform.
Eucalyptus acmenoides	5	5	1	1	uninform.
Eucalyptus crebra	2	11	4	18	uninform.
Eucalyptus deanei	3	8	4	1	uninform.
Eucalyptus eugenioides	2	8	2	12	uninform.
Eucalyptus fibrosa	4	19	4	16	uninform.
Eucalyptus haemastoma	1	3	2	3	uninform.
Eucalyptus moluccana	1	3	4	20	uninform.
Eucalyptus notabilis	2	19	2	5	uninform.
Eucalyptus paniculata	2	19	2	2	uninform.
Eucalyptus pilularis	2	30	4	12	uninform.
Eucalyptus piperita	1	3	2	7	uninform.
Eucalyptus punctata	3	30	3	24	uninform.
Eucalyptus saligna	2	5	3	2	uninform.
Eucalyptus sclerophylla	1	8	4	9	uninform.
Eucalyptus sparsifolia	1	14	3	4	uninform.
Eucalyptus tereticornis	2	3	4	26	uninform.
Eucalyptus umbra	1	3	–	0	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Ligustrum sinense	2	40	1	15	constant
Shrub stratum					
Chrysanthemoides monilifera	2	40	–	0	positive
Lantana camara	2	80	1	15	positive
Ground stratum					
Bidens pilosa	1	40	2	16	constant
Hypochaeris radicata	1	60	2	32	constant
Paspalum dilatatum	1	40	2	15	constant
Plantago lanceolata	1	40	2	26	constant
Setaria gracilis	2	40	2	26	constant
Climbers					
Myrsiphyllum asparagoides	3	40	2	22	constant

Map Unit 152:

Blue Gum High Forest

Sample Sites: (8)
Area (ha) 1750 / 1997 (± range): 3720 / 168 (±31)
Proportion Extant (± range): 4.5 (±0.8)%
No. Taxa (total / unique): 143 / 8
No. Taxa per Plot (±sd): 44.1 (±8.6)

Blue Gum High Forest is dominated by either *Eucalyptus pilularis* or *E. saligna*. *Angophora costata* is also frequently observed in remnants close to the shale/sandstone boundary, but would have occurred infrequently on deep shale soils. A relatively diverse stratum of small trees is usually present, and includes *Pittosporum undulatum*, *Elaeocarpus reticulatus* and *Allocasuarina torulosa*. Shrub species are typically mesic, such as *Breynia oblongifolia*, *Pittosporum revolutum*, *Clerodendrum tomentosum*, *Notelaea longifolia f. longifolia*, *Maytenus sylvestris*, *Polyscias sambucifolia* subsp. A and *Rapanea variabilis*. Sclerophyllous species such as *Persoonia linearis* and *Leucopogon juniperinum* occur more frequently closer to the shale/sandstone boundary. The ground stratum is often dense and contains a mixture of herb, grass and fern species including *Adiantum aethiopicum*, *Entolasia marginata*, *Lomandra longifolia*, *Calochlaena dubia*, *Dianella caerulea*, *Pseuderanthemum variabile* and *Oplismenus imbecillis*. Vine species are also frequently present, in particular *Tylophora barbata*, *Eustrephus latifolia*, *Clematis aristata* and *Pandorea pandorana*.

Blue Gum High Forest occurs mainly in areas with shale derived soil receiving more than 1050 mm rainfall per year, although it may be present in sheltered locations with lower rainfall. The community is generally confined to altitudes higher than 100 m above sea level on the Hornsby Plateau. In lower rainfall zones it grades into Map Unit 15. Approaching the shale sandstone boundary, Blue Gum High Forest grades into Map Unit 43.

Habitat:

Parent Geology: Wianamatta Shale (57%), Hawkesbury Sandstone (29%), Mittagong Formation (14%)

	Mean	(±sd)	Range
Elevation (m)	113.7	(44.1)	50–178
Slope (° above horizontal)	6.8	(5.3)	2.6–17.3
Annual Rainfall (mm)	1050	(183.1)	816–1250
Ruggedness (900m)	15.3	(2.3)	12–18
Maximum Temperature, Jan. (°C)	27.4	(1.2)	26.2–29.0
Solar Radiation, January	214.7	(5.0)	205–218

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	39.3 (16.2)	30.7 (13.7)
Small tree	86	14.7 (0.8)	20.0 (15.8)
Shrub	86	4.8 (1.3)	8.0 (4.0)
Forb	100	1.7 (1.6)	44.2 (30.2)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 17 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 34 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 17 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Acmena smithii	1	38	2	1	positive
Allocasuarina torulosa	3	75	2	11	positive
Alphitonia excelsa	2	25	1	1	positive
Angophora costata	2	63	2	19	positive
Backhousia myrtifolia	5	25	4	2	positive
Brachychiton acerifolius	1	25	1	1	positive
Elaeocarpus reticulatus	2	63	1	8	positive
Eucalyptus pilularis	5	50	4	13	constant
Eucalyptus saligna	5	50	3	2	positive
Ficus coronata	1	25	–	0	positive
Glochidion ferdinandi var. *ferdinandi*	3	38	1	2	positive
Pittosporum undulatum	3	75	2	15	positive
Shrub stratum					
Breynia oblongifolia	2	88	2	19	positive
Clerodendrum tomentosum	2	50	1	7	positive
Leucopogon juniperinus	2	75	2	18	positive
Maytenus silvestris	2	63	1	4	positive
Notelaea longifolia f. *longifolia*	2	50	1	17	constant
Persoonia linearis	2	50	2	32	constant
Pittosporum revolutum	3	75	2	9	positive
Platylobium formosum	3	50	1	1	positive
Polyscias sambucifolia subsp. *A*	3	50	2	11	positive
Rapanea variabilis	3	50	2	8	positive
Ground stratum					
Adiantum aethiopicum	3	88	3	11	positive
Asplenium flabellifolium	2	38	2	3	positive
Blechnum cartilagineum	4	50	1	2	positive
Calochlaena dubia	2	63	2	2	positive
Carex maculata	2	25	–	0	positive
Dianella caerulea	2	75	2	28	positive
Doodia aspera	3	38	2	3	positive
Entolasia marginata	3	88	2	25	positive
Entolasia stricta	1	50	3	59	constant
Hydrocotyle laxiflora	2	38	2	2	positive
Lomandra longifolia	3	100	2	31	positive
Morinda jasminoides	4	50	2	3	positive
Oplismenus aemulus	3	50	2	19	constant
Oplismenus imbecillis	2	63	2	10	positive
Oxalis perennans	1	50	2	27	constant
Poa affinis	3	63	2	7	positive
Pratia purpurascens	3	63	2	43	constant
Pseuderanthemum variabile	3	75	2	11	positive
Pteridium esculentum	2	50	2	15	constant
Viola hederacea	2	25	2	2	positive
Climbers					
Cissus hypoglauca	5	25	1	1	positive
Clematis aristata	2	63	2	6	positive
Eustrephus latifolius	3	88	2	9	positive
Glycine clandestina	2	63	2	42	constant
Marsdenia rostrata	2	38	3	1	positive
Pandorea pandorana	3	75	2	13	positive
Smilax australis	1	38	2	3	positive
Smilax glyciphylla	1	50	1	13	constant
Tylophora barbata	2	100	2	5	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora floribunda	2	38	2	7	uninform.
Corymbia gummifera	1	13	2	29	uninform.
Eucalyptus globoidea	1	25	2	8	uninform.
Eucalyptus paniculata	4	25	2	3	uninform.
Eucalyptus punctata	1	13	3	24	uninform.
Eucalyptus tereticornis	2	13	4	25	uninform.
Syncarpia glomulifera	1	13	3	20	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Cinnamomum camphora	2	29	1	1	positive
Ligustrum lucidum	3	43	1	7	positive
Ligustrum sinense	2	86	1	15	positive
Shrub stratum					
Lantana camara	2	71	1	15	positive
Ochna serrulata	2	71	1	4	positive
Rubus ulmifolius	1	29	2	1	positive
Climbers					
Passiflora edulis	1	43	1	2	positive
Passiflora subpeltata	1	29	–	0	positive

Map Unit 36:

Freshwater Wetlands

Sample Sites: Not sampled
Area (ha) 1750 / 1997 (± range): 1552 / 664 (±82)
Proportion Extant (± range): 42.8 (±5.3)%
No. Taxa (total / unique): Unknown
No. Taxa per Plot (±sd): Unknown

Freshwater Wetlands were not sampled in this survey. Benson (1992) notes that the floristic composition of wetlands is quite variable and may depend on factors such as water depth and period of inundation. Typical species in permanent or semi-permanent wetlands include *Eleocharis sphacelata*, which may form an emergent reedland over smaller species such as *Ludwigia peploides* subsp. *montevidensis*, *Triglochin procera* and *Philydrum lanuginosum* (Benson 1992). Wetlands that are only intermittently inundated may support scattered shrub species including *Melaleuca linariifolia*, *M. styphelioides* and *Casuarina glauca*. Ground species include *Juncus usitatus* and *Persicaria* spp. (Benson 1992).

Map Unit 31:

Sandstone Ridgetop Woodland

Sample Sites: (41)
Area (ha) 1750 / 1997 (± range): Not calculated
Proportion Extant (± range): Not calculated
No. Taxa (total / unique): 273 / 14
No. Taxa per Plot (±sd): 52.4 (±8.2)

Sandstone Ridgetop Woodland is dominated by *Corymbia gummifera* and *Eucalyptus sclerophylla* with *Banksia serrata* frequently present at lower abundance. A variety of other tree species occur more sporadically, including *E. punctata*, *E. oblonga* and *Angophora costata*. A diverse array of shrub species is always present, although depending on the time of the last fire a shrub stratum may not be fully developed. Shrub species frequently recorded included *Banksia spinulosa* var. *spinulosa*, *Isopogon anemonifolius*, *Leptospermum trinervium*, *Phyllanthus hirtellus*, *Dillwynia retorta* and *Eriostemon australasius* subsp. *australasius*. The ground stratum is similarly diverse and features species such as *Lomandra obliqua*, *Entolasia stricta*, *Cyathochaeta diandra*, *Dampiera stricta* and *Stipa pubescens*.

This community occurs predominantly on sandstone ridgetops and plateaux, but may extend to the floor of shallow gullies. Sandstone Ridgetop Woodland is structurally variable and may lack a tree stratum. Shrub density is highly variable, with the density of serotinous obligate seeders varying as a function of fire frequency. In steeper gullies, the community grades into Map Unit 33. Isolated patches of rock pavement heath (Keith 1994) occur sporadically within this Map Unit, predominantly along the ridge lines. In poorly drained areas Map Unit 31 abruptly changes to sedgeland. Rock pavement heath and sedgeland are floristically distinct from Map Unit 31 but were neither sampled nor described in this survey (but see Keith 1994 and French et al. 2001).

Previous floristic classifications:

Sandstone Ridgetop Woodland is equivalent to Sydney Sandstone Ridgetop Woodland described by Benson (1994). Five communities recognised by Keith (1994) based on structural variation and soil characteristics are amalgamated under this classification. These include Ironstone Heath, Ironstone Woodland, Sandstone Woodland, Heath Woodland and Mallee Heath.

Habitat:

Parent Geology: Hawkesbury Sandstone (66%), Mittagong formation (31%), Holocene alluvium (3%)

	Mean	(±sd)	Range
Elevation (m)	239.9	(104.1)	1–412
Slope (° above horizontal)	6.2	(5.2)	0–29.3
Annual Rainfall (mm)	1178.8	(159.8)	837–1509
Ruggedness (900m)	20.0	(9.0)	2–49
Terrain (900m)	10.6	(13.5)	-37–47
Maximum Temperature, Jan. (°C)	25.5	(8.1)	24.3–28.3
Solar Radiation, January	212.1	(3.9)	187–219

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	13.6 (4.8)	12.2 (5.9)
Small tree	50	5.9 (1.4)	14.5 (12.2)
Shrub	96	2.4 (1.1)	21.7 (15.2)
Forb	100	0.5 (0.6)	17.3 (15.7)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 28 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 43 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 28 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Banksia serrata	2	71	2	5	positive
Corymbia gummifera	3	93	2	25	positive
Eucalyptus haemastoma	2	22	2	2	positive
Eucalyptus oblonga	2	32	3	7	positive
Eucalyptus piperita	3	22	2	5	positive
Eucalyptus sclerophylla	4	32	4	8	positive
Shrub stratum					
Acacia linifolia	2	54	2	18	positive
Acacia myrtifolia	1	32	1	5	positive
Acacia suaveolens	2	66	1	7	positive
Acacia ulicifolia	2	59	1	22	positive
Angophora hispida	2	29	3	3	positive
Banksia ericifolia	2	24	3	2	positive
Banksia marginata	3	20	1	1	positive
Banksia spinulosa var. *spinulosa*	2	93	2	21	positive
Boronia ledifolia	1	29	1	3	positive
Bossiaea ensata	1	22	1	1	positive
Bossiaea heterophylla	2	71	2	4	positive
Bossiaea obcordata	2	32	2	11	positive
Brachyloma daphnoides	2	20	1	4	positive
Conospermum longifolium	1	34	1	1	positive
Dillwynia retorta	2	71	2	11	positive
Epacris pulchella	2	37	1	5	positive
Eriostemon australasius	2	61	2	7	positive
Gompholobium glabratum	1	27	2	3	positive
Gompholobium grandiflorum	2	44	1	4	positive
Grevillea buxifolia	2	44	1	2	positive
Grevillea diffusa subsp. *diffusa*	1	24	2	2	positive
Grevillea sericea	2	27	2	5	positive
Grevillea sphacelata	2	39	1	3	positive
Hakea dactyloides	1	73	2	14	positive
Hakea sericea	2	71	2	19	positive
Hibbertia riparia	2	20	2	1	positive
Hibbertia serpyllifolia	2	22	2	3	positive
Hovea linearis	1	56	1	14	positive
Isopogon anemonifolius	2	85	2	11	positive
Lambertia formosa	2	78	2	10	positive
Leptospermum arachnoides	1	22	2	2	positive
Leptospermum trinervium	2	90	2	25	positive
Leucopogon microphyllus var. *microphyllus*	1	29	2	2	positive
Lomatia silaifolia	1	59	1	15	positive
Micrantheum ericoides	2	37	2	6	positive
Monotoca scoparia	1	68	1	12	positive
Persoonia levis	1	98	1	20	positive
Persoonia pinifolia	1	41	1	5	positive
Petrophile pulchella	2	24	1	3	positive
Petrophile sessilis	2	54	2	5	positive
Phyllanthus hirtellus	2	80	2	32	positive
Pimelea linifolia subsp. *linifolia*	2	46	2	27	constant
Platysace linearifolia	2	61	2	10	positive
Pultenaea elliptica	1	46	2	6	positive
Xanthosia pilosa	2	44	2	11	positive
Ground stratum					
Actinotus minor	2	54	4	3	positive
Anisopogon avenaceus	2	37	2	10	positive
Billardiera scandens	1	51	1	36	constant
Caustis flexuosa	2	51	2	5	positive
Cyathochaeta diandra	3	85	2	19	positive
Dampiera stricta	2	78	2	6	positive
Entolasia stricta	2	80	3	57	positive
Lepidosperma laterale	2	49	2	44	constant
Lepyrodia scariosa	2	54	3	6	positive
Lindsaea linearis	2	32	2	5	positive
Lindsaea microphylla	1	32	1	9	positive
Lomandra cylindrica	2	44	2	15	positive
Lomandra glauca	2	44	2	7	positive
Lomandra gracilis	2	29	2	11	positive
Lomandra multiflora subsp. *multiflora*	1	54	2	50	constant
Lomandra obliqua	2	78	2	27	positive
Mitrasacme polymorpha	1	20	1	2	positive
Patersonia glabrata	2	24	2	7	positive
Patersonia sericea	1	37	1	10	positive
Platysace ericoides	2	39	2	10	positive
Ptilothrix deusta	2	27	3	5	positive

Schoenus ericetorum	1	34	2	1	positive
Stipa pubescens	2	56	3	25	positive
Tetratheca neglecta	1	32	2	1	positive
Xanthorrhoea concava	1	37	1	8	positive
Xanthorrhoea media	2	56	2	7	positive
Xanthosia tridentata	2	32	1	6	positive
Climbers					
Cassytha pubescens	2	54	2	17	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora bakeri	3	7	2	13	uninform.
Angophora costata	2	24	2	19	uninform.
Corymbia eximia	2	2	2	3	uninform.
Eucalyptus agglomerata	1	2	2	2	uninform.
Eucalyptus consideniana	3	10	–	0	uninform.
Eucalyptus globoidea	3	10	2	8	uninform.
Eucalyptus parramattensis subsp. *parramattensis*	3	2	1	4	uninform.
Eucalyptus pilularis	1	7	4	13	uninform.
Eucalyptus punctata	2	22	3	24	uninform.
Eucalyptus sieberi	3	12	–	0	uninform.
Eucalyptus sparsifolia	2	10	3	4	uninform.
Eucalyptus squamosa	2	2	2	1	uninform.
Syncarpia glomulifera	2	2	3	21	uninform.

Map Unit 32:

Upper Georges River Sandstone Woodland

Sample Sites: (59)
Area (ha) 1750 / 1997 (± range): Not calculated
Proportion Extant (± range): Not calculated
No. Taxa (total / unique): 338 / 5
No. Taxa per Plot (±sd): 51.9 (±8.5)

Upper Georges River Sandstone Woodland is dominated by *Eucalyptus punctata* and *Corymbia gummifera*, with *E. oblonga* occurring frequently at lower abundance. *Allocasuarina littoralis* is frequently present, particular on the upper slopes of gullies where it forms a small tree layer. Diverse shrub and ground strata are always present. Typical shrub species include *Acacia ulicifolia*, *A. terminalis*, *A. linifolia*, *Persoonia linearis*, *Leptospermum trinervium* and *Exocarpos strictus*. The ground stratum is often dominated by grass species such as *Entolasia stricta*, *Themeda australis*, *Stipa pubescens* *Aristida vagans* and *Danthonia linkii*. Other species frequently recorded in the ground stratum include *Dianella revoluta*, *Pomax umbellata*, *Lepidosperma laterale*, *Cyathochaeta diandra*, *Lomandra multiflora* and *Lomandra cylindrica*.

Field sampling of this community was restricted to two main areas; along the south-eastern boundary of the Cumberland Plain between Appin and Holsworthy and to the north-west between Springwood and Bowen Mountain. Map Unit 32 is most commonly found on soils of the Mittagong Formation and further sampling is warranted to verify its presence in other parts of the study area where this soil landscape occurs. South of Campbelltown, the community is restricted to within 1 km of the shale/sandstone boundary, but this zone extends to approximately 4.5 km further north. This community is typically found on upper slopes and ridges, with *E. pilularis* becoming dominant descending into the gullies. Field survey sites always contained sandy soils and sandstone outcropping was often evident. Nevertheless, a strong shale influence in the soil was implied at most sites by landscape position and proximity to the shale/sandstone boundary. Map Unit 32 grades into Map Unit 31 with increasing distance from the shale/sandstone boundary. Descending into gullies, the community grades into Map Unit 33, a transition that may be abrupt in steep sided gullies and is often associated with a break in slope.

Previous floristic classifications:

Upper Georges River Sandstone Woodland is likely to be floristically similar to Sandstone/Shale Transition community described by Benson and Howell (1994) in the Bargo area.

Habitat:

Parent Geology: Mittagong Formation (65%), Wianamatta Shale (17%), Hawkesbury Sandstone (17%), Tertiary alluvium (1%)

	Mean	(±sd)	Range
Elevation (m)	129.8	(61.8)	23–275
Slope (° above horizontal)	4.7	(4.8)	0–20.5
Annual Rainfall (mm)	932.0	(43.4)	855–1069
Ruggedness (900m)	15.5	(7.0)	3–32
Maximum Temperature, Jan. (°C)	26.8	(3.8)	25.7–27.4
Solar Radiation, January	215.1	(3.2)	200–218
Distance to Shale (m)	694.6	(774.0)	0–1536.6

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	16.3 (3.9)	21.4 (10.4)
Small tree	43	8.1 (2.3)	10.2 (6.0)
Shrub	98	2.6 (0.9)	16.3 (14.6)
Forb	100	0.6 (0.6)	26.6 (17.7)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 27 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 42 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 27 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Allocasuarina littoralis	2	66	2	21	positive
Angophora bakeri	2	34	2	11	positive
Angophora costata	2	39	2	17	positive
Corymbia gummifera	3	81	2	24	positive
Eucalyptus oblonga	2	44	3	6	positive
Eucalyptus pilularis	4	27	4	12	positive
Eucalyptus punctata	4	78	2	20	positive
Shrub stratum					
Acacia linifolia	2	63	2	16	positive
Acacia longifolia	2	20	1	8	positive
Acacia myrtifolia	1	25	1	5	positive
Acacia suaveolens	1	24	2	9	positive
Acacia terminalis	2	63	2	14	positive
Acacia ulicifolia	2	76	1	19	positive
Astroloma pinifolium	1	12	1	1	positive
Banksia spinulosa var. *spinulosa*	2	75	2	20	positive
Bossiaea obcordata	2	25	2	11	positive
Brachyloma daphnoides	2	20	1	3	positive
Dillwynia retorta	2	53	2	11	positive
Eriostemon australasius	2	41	2	6	positive
Exocarpos strictus	2	49	1	8	positive
Gompholobium minus	2	32	2	2	positive
Grevillea diffusa subsp. *diffusa*	2	15	2	2	positive
Grevillea mucronulata	2	34	2	15	positive
Grevillea sphacelata	1	19	2	4	positive
Hakea dactyloides	1	46	2	15	positive
Hakea sericea	2	54	2	20	positive
Hibbertia serpyllifolia	1	17	2	3	positive

Hovea linearis	1	63	1	13	positive
Isopogon anemonifolius	2	47	2	12	positive
Kunzea ambigua	2	37	2	15	positive
Lambertia formosa	2	31	2	12	positive
Leptomeria acida	1	17	1	4	positive
Leptospermum parvifolium	2	14	1	1	positive
Leptospermum trinervium	2	73	2	24	positive
Leucopogon ericoides	1	12	1	2	positive
Leucopogon virgatus	2	17	–	0	positive
Lissanthe strigosa	2	59	2	18	positive
Lomatia silaifolia	1	46	1	15	positive
Monotoca scoparia	2	58	1	12	positive
Persoonia levis	1	69	1	20	positive
Persoonia linearis	2	69	2	29	positive
Petrophile sessilis	2	19	2	7	positive
Phyllanthus hirtellus	2	95	2	29	positive
Pimelea linifolia subsp. *linifolia*	2	63	2	25	positive
Xanthosia pilosa	2	29	2	12	positive
Xylomelum pyriforme	1	24	1	6	positive
Ground stratum					
Acianthus fornicatus	2	20	2	4	positive
Aristida vagans	2	51	2	44	constant
Astroloma humifusum	1	19	1	7	positive
Billardiera scandens	1	81	1	33	positive
Brunoniella pumilio	2	39	2	17	positive
Cyathochaeta diandra	2	73	2	18	positive
Danthonia linkii	2	53	2	8	positive
Dianella revoluta var. *revoluta*	2	85	2	33	positive
Entolasia stricta	3	100	3	55	positive
Eragrostis benthamii	1	12	1	1	positive
Gonocarpus tetragynus	2	46	2	20	positive
Goodenia hederacea subsp. *hederacea*	1	61	2	31	positive
Helichrysum scorpioides	1	12	2	3	positive
Lepidosperma laterale	2	76	2	42	positive
Lomandra confertifolia subsp. *rubiginosa*	3	22	2	8	positive
Lomandra cylindrica	2	58	2	13	positive
Lomandra filiformis subsp. *coriacea*	2	44	2	13	positive
Lomandra multiflora subsp. *multiflora*	2	76	2	48	positive
Lomandra obliqua	2	95	2	25	positive
Patersonia glabrata	1	29	2	6	positive
Patersonia sericea	1	37	1	10	positive
Platysace ericoides	2	34	2	9	positive
Poa labillardieri var. *labillardieri*	2	41	2	15	positive
Pomax umbellata	2	76	2	32	positive
Stipa pubescens	3	78	2	22	positive
Stylidium graminifolium	1	34	2	7	positive
Themeda australis	3	68	3	56	constant
Trachymene incisa subsp. *incisa*	2	14	3	3	positive
Xanthorrhoea concava	2	44	1	7	positive
Xanthorrhoea media	2	29	2	8	positive
Climbers					
Cassytha pubescens	2	64	2	15	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Corymbia eximia	2	8	2	3	uninform.
Eucalyptus agglomerata	4	5	1	2	uninform.
Eucalyptus capitellata	1	2	–	0	uninform.
Eucalyptus crebra	1	5	3	19	uninform.
Eucalyptus eugenioides	4	5	2	12	uninform.
Eucalyptus fibrosa	4	2	4	18	uninform.
Eucalyptus globoidea	4	3	2	9	uninform.
Eucalyptus haemastoma	2	3	2	3	uninform.
Eucalyptus notabilis	1	2	2	6	uninform.
Eucalyptus paniculata	1	2	2	3	uninform.
Eucalyptus piperita	4	7	2	6	uninform.
Eucalyptus resinifera	2	10	1	4	uninform.
Eucalyptus sclerophylla	4	19	4	8	uninform.
Eucalyptus sieberi	4	2	3	1	uninform.
Eucalyptus sparsifolia	4	2	3	4	uninform.
Eucalyptus squamosa	1	7	3	1	uninform.
Syncarpia glomulifera	2	29	3	19	uninform.

Map Unit 33:

Western Sandstone Gully Forest

Sample Sites: (62)
Area (ha) 1750 / 1997 (± range): Not calculated
Proportion Extant (± range): Not calculated
No. Taxa (total / unique): 361 / 24
No. Taxa per Plot (±sd): 52.7 (±10.7)

Western Sandstone Gully Forest is dominated by *Angophora costata, Corymbia gummifera* and *E. pilularis,* with *E. punctata* occurring sporadically on mid-slopes. A sparse layer of smaller trees is usually present, and dominated by *Ceratopetalum gummiferum* and *Allocasuarina littoralis.* The shrub and ground strata are also sparse and often contain slightly fewer species relative to ridgetop communities. Shrub species include *Acacia terminalis, Leptospermum trinervium, Persoonia linearis* and *Banksia spinulosa* var. *spinulosa.* In the ground stratum, the fern species *Pteridium esculentum* is invariably present, along with the climber *Smilax glyciphylla.* These species were seldom recorded in other communities. Other species frequently recorded in the ground stratum include *Entolasia stricta, Dianella caerulea, Lomandra obliqua, L. longifolia, L. gracilis, Lepidosperma laterale* and *Gonocarpus teucrioides.*

Western Sandstone Gully Forest occurs on the lower slopes of sandstone gullies. The gradation into Map Unit 31 generally occurs less than half way up the slope from the gully floor. In particularly sheltered gullies, mesic species such as *Backhousia myrtifolia* and *Pittosporum undulatum* form a dense small tree stratum. Vines such as *Cissus hypoglauca* may also be locally abundant, and dense patches of fern such as *Calochlaena dubia* also occur. A narrow band of Riparian Scrub (Map Unit 35) usually occupies the creekline.

Previous floristic classifications:

Western Sandstone Gully Forest is equivalent to Western Gully Forest described by Keith (1994) and is included under Sydney Sandstone Gully Forest by Benson (1992).

Habitat:

Parent Geology: Hawkesbury Sandstone (82%), Mittagong Formation (18%)

	Mean	(±sd)	Range
Elevation (m)	101.2	(66.7)	4–264
Slope (° above horizontal)	17.1	(9.2)	1.3–35.0
Annual Rainfall (mm)	956.5	(66.1)	846–1081
Ruggedness (900 m)	23.1	(8.1)	11–46
Terrain (900 m)	-13.5	(20.5)	-48–54
Maximum Temperature, Jan. (°C)	26.7	(0.4)	25.9–27.4
Solar Radiation, January	205.7	(9.6)	182–218

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	22.4 (4.3)	17.8 (8.9)
Small tree	67	9.5 (3.5)	11.8 (7.1)
Shrub	86	2.8 (1.1)	18.8 (15.4)
Forb	100	0.8 (0.7)	14.3 (13.6)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 27 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 39 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 27 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Allocasuarina littoralis	2	61	2	21	positive
Allocasuarina torulosa	2	27	2	11	positive
Angophora costata	4	71	2	14	positive
Banksia serrata	2	40	2	6	positive
Ceratopetalum gummiferum	2	60	2	3	positive
Corymbia gummifera	2	81	3	24	positive
Elaeocarpus reticulatus	1	48	1	5	positive
Eucalyptus pilularis	4	65	3	8	positive
Eucalyptus piperita	3	32	2	4	positive
Shrub stratum					
Acacia linifolia	2	48	2	17	positive
Acacia longifolia	2	26	1	7	positive
Acacia suaveolens	2	35	1	8	positive
Acacia terminalis	2	66	2	13	positive
Acacia ulicifolia	1	60	1	20	positive
Amperea xiphoclada	1	11	1	1	positive
Banksia spinulosa var. *spinulosa*	2	61	2	21	positive
Boronia ledifolia	1	23	1	3	positive
Bossiaea heterophylla	2	31	2	6	positive
Bossiaea obcordata	2	29	2	10	positive
Correa reflexa var. *reflexa*	2	21	1	3	positive
Dillwynia retorta	2	39	2	12	positive
Dodonaea triquetra	2	58	2	11	positive
Epacris pulchella	1	19	1	6	positive
Eriostemon australasius	2	29	2	9	positive
Grevillea buxifolia	1	15	2	3	positive
Grevillea linearifolia	2	16	1	1	positive
Grevillea mucronulata	2	37	2	14	positive
Grevillea sericea	2	16	2	5	positive
Hovea linearis	1	32	1	15	positive
Lambertia formosa	2	37	2	11	positive
Lasiopetalum ferrugineum var. *ferrugineum*	2	10	1	2	positive
Leptomeria acida	2	23	1	3	positive
Leptospermum polygalifolium subsp. *polygalifolium*	2	18	2	6	positive
Leptospermum trinervium	2	81	2	23	positive
Leucopogon ericoides	1	10	1	2	positive
Leucopogon lanceolatus var. *lanceolatus*	1	19	1	3	positive
Logania albiflora	1	13	1	1	positive
Lomatia silaifolia	1	68	1	13	positive
Micrantheum ericoides	3	18	2	6	positive
Monotoca elliptica	1	11	1	1	positive
Notelaea longifolia f. *longifolia*	1	34	1	16	positive
Persoonia levis	1	82	1	19	positive
Persoonia linearis	2	76	2	28	positive
Persoonia pinifolia	1	19	1	6	positive
Philotheca scabra subsp. *scabra*	2	13	–	0	positive
Phyllanthus hirtellus	2	77	2	30	positive
Platysace lanceolata	3	19	2	1	positive
Platysace linearifolia	2	52	2	9	positive
Pultenaea daphnoides	3	13	-	0	positive
Pultenaea flexilis	2	24	2	2	positive
Ricinocarpos pinifolius	1	24	1	1	positive
Woollsia pungens	1	11	2	1	positive
Xanthosia pilosa	2	81	2	7	positive
Xylomelum pyriforme	1	42	1	4	positive
Ground stratum					
Acianthus fornicatus	2	24	2	4	positive
Actinotus helianthi	2	42	1	2	positive
Billardiera scandens	1	76	1	34	positive
Calochlaena dubia	3	13	2	2	positive
Caustis flexuosa	2	21	2	7	positive
Crassula sieberiana	1	11	2	3	positive
Dampiera purpurea	1	24	2	3	positive
Dendrobium linguiforme	1	13	–	0	positive
Dianella caerulea	2	89	2	23	positive
Dianella revoluta var. *revoluta*	2	52	2	36	constant
Entolasia stricta	3	94	3	55	positive
Galium binifolium	1	16	2	4	positive
Gonocarpus teucrioides	2	40	2	6	positive
Haemodorum planifolium	1	13	1	3	positive
Hybanthus monopetalus	1	10	1	2	positive
Lepidosperma filiforme	2	13	1	1	positive
Lepidosperma laterale	2	71	2	42	positive
Lindsaea microphylla	1	31	1	8	positive
Lomandra confertifolia subsp. *rubiginosa*	3	23	2	8	positive
Lomandra cylindrica	2	39	2	14	positive
Lomandra filiformis subsp. *filiformis*	1	42	2	34	constant
Lomandra gracilis	2	55	2	8	positive
Lomandra longifolia	2	71	2	28	positive
Lomandra multiflora subsp. *multiflora*	1	53	2	50	constant
Lomandra obliqua	2	79	2	26	positive
Opercularia aspera	1	27	1	3	positive
Patersonia glabrata	2	35	2	5	positive
Pomax umbellata	2	40	2	35	constant
Pteridium esculentum	2	85	2	9	positive
Schoenus melanostachys	1	13	1	2	positive
Stipa pubescens	2	47	3	25	positive
Stylidium laricifolium	2	16	1	1	positive
Stylidium productum	2	15	1	1	positive
Xanthorrhoea arborea	2	34	2	1	positive
Xanthosia tridentata	1	31	2	5	positive
Climbers					
Cassytha pubescens	1	37	2	18	positive
Hardenbergia violacea	1	48	1	29	positive
Kennedia rubicunda	1	21	1	5	positive
Marsdenia suaveolens	2	10	2	1	positive
Pandorea pandorana	1	27	2	13	positive
Smilax glyciphylla	2	77	1	7	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Angophora bakeri	2	24	3	12	uninform.
Angophora floribunda	1	2	2	8	uninform.
Corymbia eximia	3	2	2	3	uninform.
Eucalyptus agglomerata	1	5	2	2	uninform.
Eucalyptus globoidea	3	3	2	9	uninform.
Eucalyptus haemastoma	4	3	2	3	uninform.
Eucalyptus punctata	1	26	3	24	uninform.
Eucalyptus resinifera	1	6	1	4	uninform.
Eucalyptus umbra	4	2	–	0	uninform.
Syncarpia glomulifera	2	32	3	19	uninform.

Map Unit 34:

Mangrove/Saltmarsh Complex

Sample Sites: (3)
Area (ha) 1750 / 1997 (± range): Not calculated
Proportion Extant (± range): Not calculated
No. Taxa (total / unique): 15 / 9
No. Taxa per Plot (±sd): 6.3 (±7.5)

Mangrove and Saltmarsh communities were poorly sampled in this survey and were therefore amalgamated as a complex for mapping. The three sites surveyed were relatively poor in species, and only three species were recorded more than once: *Avicennia marina* var. *australasica*, *Aegiceras corniculatum* and *Sarcocornia quinqueflora* subsp. *quinqueflora*. Further sampling is required to adequately characterise the floristic composition of this complex.

Habitat:

Parent Geology: Estuarine (100%)

	Mean	(±sd)	Range
Elevation (m)	1.3	(0.6)	1–2
Slope (° above horizontal)	1.1	(0.2)	0.9–1.3
Annual Rainfall (mm)	1025.3	(59.8)	985–1094
Ruggedness (900m)	11.3	(13.7)	2–27
Maximum Temperature, Jan. (°C)	26.4	(0.6)	25.7–26.7
Solar Radiation, January	217.7	(0.6)	217–218

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	67	10.5 (2.1)	42.5 (38.9)
Small tree	33	3.0 (–)	60.0 (–)
Shrub	–	– –	
Forb	67	– –	

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 2 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 2 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 2 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Aegiceras corniculatum	2	67	–	0	positive
Avicennia marina subsp *australasica*	6	100	–	0	positive
Shrub stratum					
Goodenia ovata	1	33	3	1	positive
Senecio minimus	1	33	–	0	positive
Ground stratum					
Apium prostratum	2	33	–	0	positive
Baumea juncea	2	33	–	0	positive
Juncus kraussii subsp. *australiensis*	4	33	–	0	positive
Samolus repens	2	33	–	0	positive
Sarcocornia quinqueflora subsp. *quinqueflora*	3	67	–	0	positive
Sporobolus virginicus var. *minor*	3	33	–	0	positive
Suaeda australis	3	33	–	0	positive
Tetragonia tetragonoides	2	33	–	0	positive

Map Unit 35:

Riparian Scrub

Sample Sites: (7)
Area (ha) 1750 / 1997 (± range): Not calculated
Proportion Extant (± range): Not calculated
No. Taxa (total / unique): 173 / 15
No. Taxa per Plot (±sd): 42.7 (±11.1)

Riparian Scrub is dominated by *Ceratopetalum apetalum* and *Tristaniopsis laurina*. *Angophora costata* is frequently present along the banks of smaller streams. Along the Georges River *Eucalyptus pilularis* is more common, but this species is restricted to the river banks and was rarely recorded in a survey site. Common species recorded in the shrub stratum include *Lomatia myricoides*, *Acacia obtusifolia*, *Leptospermum morrisonii* and *Grevillea oleoides*. The shrub stratum is locally dense, but shrub patches are frequently interspersed between rock pavement, recent deposits of sediment and water. The ground stratum is similarly variable. *Schoenus melanostachys*, *Sticherus flabellatus* and *Todea barbara* occur frequently on the banks and consolidated sediments within streams. Water plants such as *Triglochin procerum* occur intermittently.

Previous floristic classifications:

Riparian Scrub was described by Keith (1994).

Habitat:

Parent Geology: Hawkesbury Sandstone (100%)

	Mean	(±sd)	Range
Elevation (m)	154.6	(111.6)	10–349
Slope (° above horizontal)	11.4	(4.7)	4.5–19.6
Annual Rainfall (mm)	1063.4	(180.2)	864–1524
Ruggedness (900 m)	26.5	(6.3)	13–34
Maximum Temperature, Jan. (°C)	26.4	(1.1)	24.6–28.5
Solar Radiation, January	207.7–4.8		198–216

Structure:

Growth form	Frequency (%)	Mean height (m) (±sd)	Mean foliage cover (%)(±sd)
Tree	100	12 (7.2)	40.3 (34.1)
Small tree	33	10.0 (–)	5.0 (–)
Shrub	67	2.5 (0.7)	10.0 (7.1)
Forb	100	1.0 (–)	20 (–)

Diagnostic Species: Positive diagnostic species are shaded. A 0.04 ha plot located in this Map Unit is expected to contain at least 31 positive diagnostic species (95% confidence interval) provided the total number of native species in the plot is 10 or greater. A 95% confidence interval means that five percent of plots sampled (1 in 20 plots) in this Map Unit may contain fewer than 31 positive diagnostic species.

C/A: Cover/abundance within Map Unit (50 percentile)
Freq: Frequency (%) within Map Unit
C/A O: Cover/abundance in other Map Units (50 percentile)
FreqO: Frequency (%) within other Map Units
FC: Fidelity class

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Allocasuarina littoralis	3	43	2	24	constant
Angophora costata	3	43	2	19	constant
Backhousia myrtifolia	3	29	4	2	positive
Ceratopetalum apetalum	3	71	–	0	positive
Ceratopetalum gummiferum	3	57	2	7	positive
Stenocarpus salignus	2	57	1	1	positive
Tristania neriifolia	2	29	–	0	positive
Tristaniopsis laurina	4	86	1	1	positive
Shrub stratum					
Acacia floribunda	2	43	2	7	positive
Acacia longissima	1	29	1	1	positive

Acacia obtusifolia	4	29	–	0	positive
Acacia terminalis	2	43	2	17	constant
Banksia marginata	1	29	2	2	positive
Daviesia corymbosa	2	57	1	1	positive
Dodonaea triquetra	2	43	2	14	constant
Grevillea mucronulata	2	43	2	16	constant
Grevillea oleoides	3	43	–	0	positive
Hakea salicifolia	3	29	1	1	positive
Lasiopetalum ferrugineum var. *ferrugineum*	1	29	2	2	positive
Leionema dentatum	1	43	–	0	positive
Leptospermum morrisonii	3	43	–	0	positive
Leptospermum polygalifolium subsp. *polygalifolium*	2	43	2	7	positive
Logania albiflora	3	29	1	1	positive
Lomatia myricoides	3	100	2	1	positive
Micrantheum hexandrum	2	29	–	0	positive
Pomaderris ferruginea	2	29	1	1	positive
Westringia longifolia	2	29	1	1	positive
Ground stratum					
Baumea juncea	2	29	–	0	positive
Billardiera scandens	1	43	1	37	constant
Blechnum cartilagineum	2	29	1	2	positive
Calochlaena dubia	3	29	2	3	positive
Caustis pentandra	2	29	1	1	positive
Entolasia stricta	2	86	3	58	constant
Gleichenia dicarpa	2	43	–	0	positive
Gonocarpus teucrioides	1	57	2	8	positive
Lepidosperma laterale	1	71	2	44	constant
Lomandra fluviatilis	4	29	–	0	positive
Lomandra longifolia	2	71	2	31	constant
Morinda jasminoides	2	29	2	3	positive
Pteridium esculentum	2	43	2	15	constant
Schoenus melanostachys	2	71	1	2	positive
Sticherus flabellatus	4	57	–	0	positive
Todea barbara	2	43	–	0	positive
Triglochin procerum	2	29	–	0	positive
Viola hederacea	2	29	2	2	positive
Xanthosia tridentata	1	71	2	7	positive
Climbers					
Cassytha glabella f. *glabella*	1	43	2	16	constant
Cassytha pubescens	3	43	2	19	constant
Smilax glyciphylla	1	57	1	13	positive

Other tree species occurring less frequently in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Tree stratum					
Eucalyptus pilularis	2	29	4	13	uninform.
Eucalyptus piperita	1	29	2	6	uninform.
Eucalyptus punctata	1	14	3	24	uninform.
Eucalyptus saligna × *botryoides*	1	14	–	0	uninform.

Weed species commonly found in this community:

Species	C/A	Freq	C/AO	FreqO	FC
Ground stratum					
Ageratina adenophora	1	33	–	0	positive
Andropogon virginicus	1	33	1	1	positive
Cirsium vulgare	1	67	1	34	constant
Myriophyllum aquaticum	1	33	–	0	positive
Senecio madagascariensis	2	67	2	52	constant
Senecio vulgaris	2	33	–	0	positive
Tradescantia zebrina	1	33	–	0	positive

Appendix 2: Frequency (%) with which native species were recorded in each Map Unit (blank cells indicate the species was not recorded).

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Native species																						
Abutilon oxycarpum												23										
Acacia binervata		5				14	5															
Acacia binervia	14					7										44						
Acacia brownii		3		7	3	3	3											4		54	50	
Acacia buxifolia								1														
Acacia bynoeana																				4		
Acacia decurrens			2	5	14	24	45	19	7	9	12		10	5		22	32	11	14			
Acacia echinula																		4				
Acacia elata					3							8										
Acacia elongata				2		1	11											29	29	46	50	
Acacia falcata				3	27	23		17	5	14				3			40	50		12		
Acacia falciformis						1	3							5			8					
Acacia fimbriata						1		1										4				
Acacia floribunda	43	3		2	11	9	11	1		41	12	8		32		44			14			
Acacia hispidula		3	10	3																		
Acacia implexa				2	24	20	13	11	57	5	38	54	40	11				4				
Acacia irrorata subsp. *irrorata*				2			8		2													
Acacia leiocalyx subsp. *leiocalyx*						1		1														
Acacia linifolia	29	48	54	63	30	6				5				3				4				
Acacia longifolia	14	26	12	20	32	9				5								7		4		
Acacia longissima	29	2				1	3	1		5	12						8					
Acacia maidenii												15										
Acacia mearnsii																11						
Acacia myrtifolia		8	32	25	14	3																
Acacia obtusifolia	29	2				1																
Acacia paradoxa						1																
Acacia parramattensis		2		2	43	34	13	23	16	59	12	15	20	84		11	40	14	14	12		
Acacia parvipinnula		3		2	3	6	3										4	11				
Acacia penninervis												8										
Acacia pubescens					3			1										25				
Acacia stricta					5																	
Acacia suaveolens		35	66	24	5	1																
Acacia terminalis	43	66	32	63	11	19	3															
Acacia trinervata					3	1																
Acacia ulicifolia		60	59	76	30	24	3	1			12							7			50	
Acaena echinata												8										

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Acaena novae-zelandiae													10									
Acianthus fornicatus		24	12	20		9																
Acianthus pusillus				2																		
Acmena smithii					3					5	38	8										
Acronychia oblongifolia												8										
Acrotriche divaricata	14	3		7	3	9	3			5	12											
Actinotus helianthi		42	15	5																		
Actinotus minor	14	10	54	3																		
Adiantum aethiopicum	29	3			22	7	8		7	55	88	100	40	43		22			14			
Adiantum formosum										5												
Adiantum hispidulum							3		2	9	12											
Aegiceras corniculatum																						67
Agrostis aemula					3			3														
Agrostis avenacea var. *avenacea*					3	1	11	23	10					24	100		36	7	71	4		
Ajuga australis						1	11	17	25				10				16					
Alchornea ilicifolia												8										
Alectryon subcinereus										9	12	62										
Allocasuarina distyla		2	5																			
Allocasuarina littoralis	43	61	39	66	22	50	37	5									16	18		4		
Allocasuarina torulosa	14	27		8	46	19	8	2		14	75	31		5			8					
Alphitonia excelsa					3				2	5	25	15		3				4				
Alternanthera denticulata						1		1	3	5				16	100				29	4		
Alternanthera species *A*									2													
Amperea xiphoclada		11	10	5																	50	
Amphipogon strictus var. *strictus*																				8		
Amyema gaudichaudii						1	3	3									12	18	14	12		
Amyema miquelii								3	2				10				4	4				
Amyema pendulum subsp. *pendulum*			2				3							3								
Angophora bakeri		24	7	34		27	3	1									4	7		73	100	
Angophora costata	43	71	24	39	54	10				23	62											
Angophora floribunda		2			14	9	16	8	3	9	38	8		32		22	8	7	14			
Angophora hispida		3	29	7																		
Angophora subvelutina								5	2					14		44	4	4	29			
Anisopogon avenaceus		23	37	17	14	10	5	1		5								7		4		
Aotus ericoides	14		12																			
Aphanopetalum resinosum												62	20	3								
Apium prostratum																						33
Aristida benthamii var. *spinulifera*			2	7		3																

Typical Soil Type:	**Sandstone**				**Sandstone/Shale**			**Shale**						**Alluvium**			**Tertiary alluvium**				**Sand**	**Marine**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Aristida calycina var. *calycina*							13		2											4		
Aristida jerichoensis																				4		
Aristida ramosa			7	2	8	7	18	55	84				30	5		11	20	18	14	50		
Aristida vagans		23	2	51	49	90	53	91	23			8		8			88	71	43	50		
Aristida warburgii				7	3	4											4			58		
Arthropodium milleflorum		2			5	19	18	45	38	14	12	23	50	32		11	36	14	14	19		
Arthropodium minus						4		8	5	5		8		3			4					
Arthropodium species *B*		2		2		3		3	2								4					
Asperula conferta							8	32	61					8			4		14			
Asplenium australasicum f. *australasicum*					3					5												
Asplenium flabellifolium		6									38	62	30	8								
Astroloma humifusum		2	2	19		20	21	13	2							11	20	7		4		
Astroloma pinifolium		6		12		7																
Astrotricha floccosa					3																	
Astrotricha latifolia		3									12	8				11						
Astrotricha longifolia				2																		
Austrodanthonia bipartita		13	7	53		21	18	6	15								4	4		8		
Austrodanthonia caespitosa						1			10					5				7				
Austrodanthonia laevis							3		2													
Austrodanthonia pilosa								4	3													
Austrodanthonia racemosa var. *obtusata*									2													
Austrodanthonia racemosa var. *racemosa*		2			3	3	3	30	31			23	30	22		11	16	4				
Austrodanthonia setacea								1		5												
Austrodanthonia tenuior		2		2	11	13	5	43	23					11		11	52	61	57	15		
Austromyrtus tenuifolia	14																					
Austrostipa nodosa							3						10									
Austrostipa pubescens		47	56	78	22	56	3		3								4	11		27		
Austrostipa ramosissima						1	5			14	12	15	10	14		78						
Austrostipa rudis		2			22	4	8	6		18				8			12	7		8		
Austrostipa scabra						1	3															
Austrostipa setacea							3		3								4					
Austrostipa verticillata					3		5		2													
Avicennia marina subsp. *australasica*																						100
Azolla filiculoides var. *rubra*															50							
Babingtonia pluriflora						1																
Backhousia myrtifolia	29				5	1	3			9	25	15		5		33						

Typical Soil Type:	**Sandstone**				**Sandstone/Shale**			**Shale**						**Alluvium**			**Tertiary alluvium**				**Sand**	**Marine**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Baeckea diosmifolia																				4	50	
Baeckea imbricata			2																			
Baeckea linifolia	14	2																				
Baeckea ramosissima subsp. *ramosissima*			7		3																	
Banksia aemula																					50	
Banksia cunninghamii			2																			
Banksia ericifolia	14	3	24																	4		
Banksia integrifolia var. *integrifolia*		2																				
Banksia marginata	29	3	20																			
Banksia oblongifolia		3	15	5														4		35	100	
Banksia serrata	14	40	71	7																		
Banksia spinulosa var. *spinulosa*	14	61	93	75		1												4		81		
Bauera rubioides	14	2																				
Baumea juncea	29																					33
Bertya pomaderroides		2																				
Beyeria lasiocarpa	14																					
Beyeria viscosa	14	2		3												11						
Billardiera scandens	43	76	51	81	62	71	21			18				3		22	16	39		8		
Blandfordia nobilis			2																			
Blechnum ambiguum	14																					
Blechnum cartilagineum	29	6			5	1				18	50											
Blechnum nudum											12											
Bolboschoenus caldwellii														3								
Boronia ledifolia		23	29	10																		
Boronia pinnata			10																			
Boronia polygalifolia						6	5	1									8	18		27		
Boronia ruppii			2																			
Bossiaea buxifolia						1											4	4				
Bossiaea ensata			22	8																		
Bossiaea heterophylla	14	31	71	8																	50	
Bossiaea lenticularis						1																
Bossiaea obcordata		29	32	25	5	7																
Bossiaea prostrata		2	2	10	5	10	29	16	7								12	4		4		
Bossiaea rhombifolia subsp. *rhombifolia*		3		3																23	50	
Bossiaea scolopendria		2	5																			
Bossiaea stephensonii		2																				

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Bothriochloa decipiens								11	2													
Bothriochloa macra							3	15	28					3								
Brachychiton acerifolius					8					18	25											
Brachychiton populneus						3	5	1	7			23	50				4					
Brachycome angustifolia var. *angustifolia*						6	3	1	3			8	10	3			4	4		8		
Brachycome graminea					3	1					12							4				
Brachycome multifida								2														
Brachyloma daphnoides		3	20	20		1											4	4		12	50	
Bracteantha bracteata						1		1						5								
Breynia oblongifolia	14	11		2	38	23	37	18	16	64	88	85	80	30		22	8			4		
Brunoniella australis				2	5	24	68	88	85	18	38	15	60	54	50		60	36	14	12		
Brunoniella pumilio		13	10	39	19	29	11	6	16	18	12			11			28	21	43	38		
Burchardia umbellata		2	2	3																31		
Bursaria lasiophylla var. *atriplicina*		2																				
Bursaria spinosa	14	16		5	51	60	74	97	92	32	25	15	70	100	50	22	84	46	43	4		
Caesia parviflora		2	5	5	5	16	11	19	23	9	12			22			12	14	14	31		
Calandrinia calyptrata						1																
Calandrinia pickeringii								1														
Caleana major		2																			50	
Callicoma serratifolia	14									5												
Callistemon citrinus	14	2																			50	
Callistemon linearifolius					3																	
Callistemon linearis				10			8	1										4		8	50	
Callistemon pinifolius				2													4	7		38		
Callistemon salignus										9		15		3		11	4		14			
Callitriche muelleri	14																					
Calochlaena dubia	29	13		2	5					14	62			5								
Calotis cuneifolia					5		3	8						3			20	21	14			
Calotis dentex						26	34	4						3			4	4				
Calotis lappulacea								2	7													
Calystegia marginata										5												
Calytrix tetragona	14	2	2			1																
Capillipedium parviflorum								1	2													
Capillipedium spicigerum									3													
Cardamine paucijuga								2	3					11	50							
Carex appressa									2			15		11	100	11			14			
Carex breviculmis					5	4	3	5	7				10	8			4					

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Carex declinata												8		3								
Carex inversa					3	1	3	18	62	14		23	50	8		22	4		29			
Carex longebrachiata							3		3			23		14		22						
Carex maculata											25											
Cassine australis var. *australis*										5		15										
Cassinia aculeata				2		1												7				
Cassinia arcuata																		4				
Cassinia aureonitens		2																				
Cassinia cunninghamii						3																
Cassinia longifolia		6																				
Cassinia trinerva		2									12			3								
Cassinia uncata						1											4	11				
Cassytha glabella forma *glabella*	43	21	24	19	14	24	8	2		5	25					22	4	46	14	58	50	
Cassytha pubescens	43	37	54	64	11	17		1									4	25	14	35	50	
Casuarina cunninghamiana subsp. *cunninghamiana*												8		5								
Casuarina cunninghamiana × glauca														3								
Casuarina glauca								1	3					32	50		8					33
Caustis flexuosa		21	51	10																		
Caustis pentandra	29	2	7																			
Cayratia clematidea							11	3	5	45	38	92	80	19		33						
Celastrus australis									3			31	30									
Centaurium spicatum								5	7					3			4					
Centella asiatica	14				16	4	11	20	15	23	12			49	50	11	16	4	86			
Centipeda cunninghamii														3								
Centipeda minima var. *minima*					3									11	50			4	43			
Centrolepis fascicularis					3																	
Centrolepis strigosa subsp. *strigosa*																				4		
Ceratopetalum apetalum	71	2																				
Ceratopetalum gummiferum	57	60	10	12							12											
Chamaesyce dallachyana									2													
Chamaesyce drummondii								1	3													
Cheilanthes distans		15				4	8	2	31			8	40	3								
Cheilanthes sieberi subsp. *sieberi*		24	2	37	54	81	87	87	69	9		15		51		11	92	89	86	58		
Chenopodium carinatum													10									
Chiloglottis formicifera										5												
Chloris divaricata var. *divaricata*									2													
Chloris truncata							3	5	20			8	30	3								

Typical Soil Type:	**Sandstone**				**Sandstone/Shale**			**Shale**						**Alluvium**			**Tertiary alluvium**				**Sand**	**Marine**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Chloris ventricosa						1		18	41			15	20	8								
Chorizandra cymbaria	14			2																		
Chorizema parviflorum						3		8									28			4		
Christella dentata											12											
Chrysocephalum apiculatum					3	1		8	3								4			4		
Cissus antarctica					3					18		46	20									
Cissus hypoglauca	14			2						14	25											
Citriobatus pauciflorus										5		23										
Claoxylon australe												8										
Clematis aristata		13			11	10	5		3	32	62	15	10	8				4				
Clematis glycinoides var. *glycinoides*				2	27	10	18	9	31	59	12	31	40	49		33	4	4				
Clerodendrum tomentosum					5	6	16	5	3	36	50	62	70	11								
Comesperma defoliatum				3																		
Comesperma ericinum			7	3																		
Comesperma sphaerocarpum																		11		12		
Comesperma volubile		2		2	3	3																
Commelina cyanea					16	3	16	24	16	27		38	40	59	50	33	12	4				
Conospermum ellipticum			2																			
Conospermum ericifolium			2																			
Conospermum longifolium			34	2		1																
Conospermum taxifolium			2																		100	
Convolvulus erubescens								4	3			8		5								
Coopernookia barbata		3		2																		
Correa reflexa var. *reflexa*		21	2	3	19	3	3															
Corybas aconitiflorus				2																		
Corymbia eximia		2	2	8	5	7																
Corymbia gummifera		81	93	81	27	29	3				12									12		
Corymbia maculata						13	11	5	3			23	20	3			4					
Cotula australis								1					10	5								
Crassula sieberiana		11		2			5	2	13			8	30				4					
Croton verreauxii																11						
Crowea saligna		2	2																			
Cryptandra amara var. *amara*			10	2		4											4			23		
Cryptandra ericoides			2																			
Cryptandra propinqua				2																		
Cryptandra spinescens							11										4		14			
Cryptocarya glaucescens												8										
Cryptostylis erecta						1																

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	35	33	31	32	43	2	1	10	9	15	152	13	14	11	5	12	103	3	4	6	8	34
Cryptostylis subulata											12											
Cupaniopsis anacardioides											12											
Cuscuta australis																		7				
Cyathea australis					3					5												
Cyathea cooperi										5												
Cyathea leichhardtiana	14																					
Cyathochaeta diandra		27	85	73	8	11											8	11		88	50	
Cymbidium suave		3		2	8																	
Cymbonotus lawsonianus								8	7													
Cymbopogon refractus				5	22	20	39	47	25	5		15	20	5		11	36	11		8		
Cynanchum elegans												15										
Cynodon dactylon	14			2	8	1	13	9	8	5				14	100	22		7		4		
Cynoglossum australe													10									
Cyperus enervis								2	3			23	10	5		22						
Cyperus exaltatus								1														
Cyperus flaccidus																			14			
Cyperus fulvus									2													
Cyperus gracilis					3	3	11	17	48	5		31	70	24			4					
Cyperus gunnii subsp. *gunnii*									2					3			4		14			
Cyperus haspan subsp. *haspan*																				4		
Cyperus imbecillis		3			3			1	2			31	20	3								
Cyperus laevis					5	3	8	4	2	14		8	10	3				4				
Cyperus sanguinolentus																			14			
Cyperus tetraphyllus										5												
Cyperus trinervis														3								
Dactyloctenium radulans									2													
Damasonium minus															100							
Dampiera purpurea		24	5	8		13												4				
Dampiera stricta		6	78	14																35		
Darwinia fascicularis	14																					
Daucus glochidiatus								9	5			8										
Davallia solida var. *pyxidata*		2												3								
Daviesia acicularis						3														4		
Daviesia corymbosa	57	2	10	5																		
Daviesia genistifolia								1	2													
Daviesia squarrosa			5	2	5	4													14	42		
Daviesia ulicifolia		3		3	14	21	11	39	2								68	50		54		
Deeringia amaranthoides												31	10									

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	35	33	31	32	43	2	1	10	9	15	152	13	14	11	5	12	103	3	4	6	8	34
Dendrobium linguiforme	14	13									12											
Dendrobium speciosum		2																				
Dendrophthoe vitellina					5													11				
Desmodium brachypodum						4	5	18	46			15	70	22			12	4				
Desmodium rhytidophyllum					3	14	11	9	11	9			20	8			8					
Desmodium varians				2	16	23	63	84	82	41	25	54	100	57		22	68	14				
Deyeuxia quadriseta				3	5													4				
Dianella caerulea	29	89	22	34	78	44	16	2		73	75			14		11	4	4				
Dianella longifolia			2		8	9	29	60	33	18	12	8		30		11	52	11	43	8		
Dianella prunina			10																			
Dianella revoluta var. *revoluta*	29	52	22	85	43	54	11	32	8								56	82	14	77	50	
Dichanthium sericeum								4	16				20				8					
Dichelachne crinita																22		4				
Dichelachne inaequiglumis		2			14																	
Dichelachne micrantha		8		15	35	47	29	72	61	9	12	8	10	16		22	68	43	43	23		
Dichelachne parva						1	16	13	11	5							12					
Dichelachne rara		2		2	11			3	2										14			
Dichondra repens				2	57	33	79	98	97	77	25	69	100	97		78	68	32	71			
Dichopogon fimbriatus								5									12	4				
Dichopogon strictus								8														
Digitaria breviglumis				2														4		8		
Digitaria diffusa							5	5		9							4					
Digitaria parviflora		5			24	20	37	14	2	14	12		10	5			8	11		12		
Digitaria ramularis	14	6		12		39	13	6	2					3			4					
Dillwynia floribunda		5	7	3																8	50	
Dillwynia glaberrima								1									4			12		
Dillwynia parvifolia				8	3	6											4	14				
Dillwynia phylicoides						1																
Dillwynia retorta	14	39	71	53		13											4					
Dillwynia sericea			15	3														4		15	100	
Dillwynia sieberi						3		33	5								24	18				
Dillwynia tenuifolia						1		2									4	46	14	58		
Diospyros australis												15										
Dipodium punctatum		2			3			1														
Dipodium variegatum						1																
Dodonaea falcata																		21		4		
Dodonaea triquetra	43	58	20	17	38	23	5			9	25					22		7				
Dodonaea viscosa subsp. *angustifolia*						3	3	1														

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Dodonaea viscosa subsp. *cuneata*		2	5			1		12	11								4					
Doodia aspera					8		3			36	38	31		11								
Doodia caudata									2			15	10	14								
Doryanthes excelsa		8																				
Drosera auriculata						1											4			15		
Drosera peltata			5	2	3																	
Drosera spatulata	14	2																		4		
Duboisia myoporoides											12											
Echinopogon caespitosus var. *caespitosus*		11		20	32	73	24	46	5	32	12	8	10	19			48	29	29	23		
Echinopogon ovatus	14			5	51	19	87	38	48	55	38	46	50	84	50	67	52	25	29	23		
Eclipta platyglossa									5					8	50				14			
Ehretia acuminata var. *acuminata*												8										
Einadia hastata					8	11	18	26	15	23		23	50	30		22		14				
Einadia nutans						3	5	5	30			15	30	3		22	4					
Einadia polygonoides							5	2	13				30	3								
Einadia trigonos					3	4	13	12	23	9		15	10	19		22	4					
Elaeocarpus reticulatus		48	7	5	16	4				36	62			3								
Elatine gratioloides															50							
Eleocharis acuta									2					3								
Eleocharis cylindrostachys														3	50				14			
Eleocharis dietrichiana																			14			
Eleocharis philippinensis																				4		
Eleocharis sphacelata															50							
Elymus scaber var. *scaber*								4	20			8										
Entolasia marginata	14	3			54	29	76	26	11	82	88	23		89	50	44	12	11	14			
Entolasia stricta	86	94	80	100	78	90	32	18	2	45	50	8		5			80	96	57	96		
Epacris longiflora	14	3		2																		
Epacris microphylla var. *microphylla*		2	15	2																		
Epacris pulchella	29	19	37	8	8	1																
Epacris purpurascens var. *purpurascens*					3																	
Epaltes australis						1		1											43	12		
Epilobium billardierianum subsp. *cinereum*		2																	14			
Eragrostis benthamii		2		12		4										11						
Eragrostis brownii			2	17	22	39	18	31	10					3		11	36	54	57	77		
Eragrostis elongata						1		1											29	12		

Typical Soil Type:	**Sandstone**				**Sandstone/Shale**			**Shale**						**Alluvium**			**Tertiary alluvium**				**Sand**	**Marine**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Eragrostis leptostachya		3		5	11	21	71	68	34	14		8	10	38		11	32	4	43			
Eragrostis parviflora				2				2						3								
Eremophila debilis								35	31					8								
Eriochloa pseudoacrotricha								6	10						50				14			
Eriostemon australasius		29	61	41																		
Erodium crinitum						1																
Eucalyptus acmenoides					5					23												
Eucalyptus agglomerata		5	2	5		1																
Eucalyptus amplifolia								5	5					46	50				29			
Eucalyptus baueriana								1						5		11						
Eucalyptus benthamii																22						
Eucalyptus beyeriana						1														4		
Eucalyptus bosistoana								1														
Eucalyptus botryoides																33						
Eucalyptus capitellata				2																		
Eucalyptus consideniana			10																			
Eucalyptus crebra				5	11	57	39	31	31				30				36	4				
Eucalyptus deanei					8					5				3								
Eucalyptus elata														3		33						
Eucalyptus eugenioides				5	8	19	42	22	13	5				19			24	14	14	4		
Eucalyptus fibrosa				2	19	39	39	19	2								64	82	29	27		
Eucalyptus globoidea		3	10	3	41	17	13	1		9	25			8			12	4				
Eucalyptus haemastoma		3	22	3	3	1																
Eucalyptus longifolia						4		2										29		4		
Eucalyptus moluccana					3	1	24	69	70	5		8	60	14			40	7				
Eucalyptus notabilis				2	19	4																
Eucalyptus oblonga			32	44		16												4				
Eucalyptus paniculata				2	19	1		2		45	25											
Eucalyptus parramattensis subsp. *parramattensis*			2															7	57	77		
Eucalyptus pilularis	29	65	7	27	30	14	3			36	50	8										
Eucalyptus piperita	29	32	22	7	3									3								
Eucalyptus punctata	14	26	22	78	30	61	34	4		32	12			8			8					
Eucalyptus resinifera		6		10	32	7	5			5								4				
Eucalyptus saligna					5		3			50	50											
Eucalyptus saligna × botryoides	14															11						
Eucalyptus sclerophylla			32	19	8	6								3			8	7	14	69	100	
Eucalyptus sideroxylon							3											4	14	15		

Typical Soil Type:	**Sandstone**				**Sandstone/Shale**			**Shale**						**Alluvium**			**Tertiary alluvium**				**Sand**	**Marine**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Eucalyptus sieberi			12	2																		
Eucalyptus sparsifolia			10	2	14												4					
Eucalyptus squamosa			2	7																		
Eucalyptus tereticornis					3	9	53	67	70	5	12	38	60	46		11	40	7	29			
Eucalyptus umbra		2			3																	
Euchiton gymnocephalus		2				1		1									4		29	8		
Euchiton involucratus					5		3	1	3									4				
Euchiton sphaericus		2			3	20	39	47	39			23	20	11			40	11	43	4		
Eustrephus latifolius	14	3			32		3			86	88	85	10	11				7				
Exocarpos cupressiformis		3		5	24	26	8	24	11	18	38	8		11			8	18		8		
Exocarpos strictus		19	15	49	8	30	5										8					
Ficus coronata											25	8										
Ficus rubiginosa												8										
Fimbristylis dichotoma						1	11	27	16								28	4	57	8		
Fimbristylis velata														3								
Gahnia aspera					14	20	29	5		9	12			8		22		4				
Gahnia clarkei					3						12											
Gahnia filifolia						1																
Gahnia melanocarpa										5												
Gahnia microstachya																				4		
Gahnia radula			2																	4		
Gahnia sieberiana	14	2	5				3															
Galium australe								1														
Galium binifolium	29	16		3	14	11	8				12	8										
Galium gaudichaudii						1		4	3								8					
Galium migrans									15			8	10	8								
Galium propinquum					3	3	39	10	23	9		46	70	35		11	4	4				
Geitonoplesium cymosum	14				11	3	16		3	14	25	92	20	24								
Geranium homeanum					5			4	15	14		46	30	3								
Geranium solanderi var. *solanderi*		2			3			1	15	23		8	10	11		11						
Gleichenia dicarpa	43	2		2																		
Gleichenia microphylla	14																					
Glochidion ferdinandi var. *ferdinandi*		6	2	2	16	3				9	38	8										
Glochidion ferdinandi var. *pubens*					3					5												
Glossogyne tannensis								10	3													
Glyceria australis															50							
Glycine clandestina		10		24	78	77	47	49	38	41	62	38	80	54		56	68	46	29	23		
Glycine microphylla		8		7	30	21	16	37	39	32				35		22	32	18	14	8		

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Glycine species *A*						1	3	1	2			8				11	4					
Glycine tabacina		10		17	5	26	53	67	56	32		15	10	57		22	16	4		4		
Gompholobium glabratum			27	12		1			2											4		
Gompholobium grandiflorum		13	44	10																		
Gompholobium huegelii					3	6														8	50	
Gompholobium inconspicuum				3	3	10	3													19		
Gompholobium latifolium		3	17	7																		
Gompholobium minus		3	7	32	3	3											4			12		
Gompholobium pinnatum						3														27		
Gompholobium uncinatum				3			3															
Gonocarpus longifolius	14															22						
Gonocarpus micranthus																				4		
Gonocarpus tetragynus		10	10	46	49	44	18	3		23				3			20	39		81		
Gonocarpus teucrioides	57	40	17	15	3	3	3			5	12							7		4		
Goodenia bellidifolia subsp. *bellidifolia*		2	10	14		6												11		35		
Goodenia decurrens				2																		
Goodenia hederacea subsp. *hederacea*		24	24	61	49	49	39	48	8								68	61		35		
Goodenia heterophylla		3	2	5	5	1																
Goodenia ovata					3					9				3								33
Goodenia paniculata				5				1									4	4	100	27		
Gratiola pedunculata																			71			
Grevillea sphacelata		2	39	19																		
Grevillea arenaria							3															
Grevillea buxifolia subsp. *buxifolia*		15	44	2																		
Grevillea diffusa subsp. *diffusa*			24	15																		
Grevillea juniperina								2									12	18		4		
Grevillea linearifolia		16	5	7	3	1																
Grevillea longifolia		3		2																		
Grevillea mucronulata	43	37	29	34	3	23												14		73		
Grevillea oleoides	43	2	2																			
Grevillea sericea		16	27	8	3															4		
Grevillea speciosa		2	2																			
Guioa semiglauca											12	15										
Guringalia dimorpha	14																					
Haemodorum corymbosum	14	8	5															4		8	50	
Haemodorum planifolium		13	5	5					2								8			35		

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Hakea dactyloides	14	31	73	46	3	3														77		
Hakea gibbosa			2																			
Hakea propinqua		2																				
Hakea salicifolia	29			2	8																	
Hakea sericea	29	35	71	54	22	14								3			24	32	29	81		
Hakea teretifolia			7																			
Haloragis heterophylla								1	5					8					29			
Hardenbergia violacea	29	48	10	31	49	47	13	45	28	27	12	8	30	5			48	21	14	35		
Helichrysum collinum				3																		
Helichrysum scorpioides			2	12	14	6	3										8			8		
Hemarthria uncinata var. *uncinata*				2										5					29	4		
Hibbertia acicularis		2				6																
Hibbertia aspera		11	10	19	51	40	42	4		23	38			5		11	20	32	29	4		
Hibbertia bracteata		3	15	3																		
Hibbertia circumdans		2																				
Hibbertia cistiflora subsp. *cistiflora*		2																				
Hibbertia dentata		2			5					14												
Hibbertia diffusa		2	5	24	24	36	29	17	5					11		22	28	14		8		
Hibbertia empetrifolia	14	2	10		5	1				5								7				
Hibbertia fasciculata																				4	50	
Hibbertia linearis		2	7				3															
Hibbertia monogyna		5	10																			
Hibbertia obtusifolia						3																
Hibbertia pedunculata						3											8	4				
Hibbertia riparia		2	20	5		1																
Hibbertia scandens										9	12											
Hibbertia serpyllifolia			22	17														4		8		
Hovea linearis		32	56	63		13												4		31		
Hovea longifolia		2																		8		
Hovea purpurea		2																				
Hybanthus monopetalus		10		7	3	3	5															
Hybanthus vernonii				2		1																
Hydrocotyle laxiflora					3	4				9	38			11		22		7				
Hydrocotyle peduncularis					19	9	21	13	2	18	12		10	8			44		71	8		
Hydrocotyle tripartita	14											8		3								
Hymenanthera dentata	14						8		3			54		5		67						
Hypericum gramineum				3	16	17	29	34	39				10	5			56	36	71	54		
Hypericum japonicum				2		3	3															

Typical Soil Type:	**Sandstone**				**Sandstone/Shale**			**Shale**						**Alluvium**			**Tertiary alluvium**				**Sand**	**Marine**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Hypolepis muelleri					3					5				3								
Hypoxis hygrometrica			2			14	18	33	25					5			12	4	57	4		
Hypoxis pratensis var. *pratensis*						4		6		5				3			8		14			
Imperata cylindrica var. *major*		19		17	54	21	8	2		32	38	8		8			4	4	29	12		
Indigofera australis					11	4	8	17	16	14	25	8	30				4					
Isolepis inundata														8	50				43	4		
Isolepis nodosa	14													5					14			
Isopogon anemonifolius		19	85	47														4		38	50	
Isopogon anethifolius	14		7																		50	
Jacksonia scoparia		3		7		29	5	2	2								12	7		4		
Joycea pallida					3	1			2									4				
Juncus australis																			14			
Juncus continuus	14													8						8		
Juncus fockei																			14			
Juncus homalocaulis							3	1	8					5			4					
Juncus kraussii subsp. *australiensis*																						33
Juncus planifolius	14				3									5	50			4	43	8		
Juncus prismatocarpus	14													3				4	29			
Juncus remotiflorus								2									4	4	14			
Juncus subsecundus									2										14			
Juncus usitatus	14						5	28	18	5		15		35	100		20	7	86	4		
Juncus vaginatus					5																	
Kennedia rubicunda	14	21		3	22	13	3	2		23	25	8										
Kunzea ambigua	14	11	17	37	22	60	45	2	2	5				3		11	4	21	14	4		
Kunzea capitata			5	5																19	50	
Kunzea parvifolia																				4		
Lagenifera gracilis		6		24	3	40	42	15	8	5		8	30	5			12	7		12		
Lagenifera stipitata		2			3	6	11	3	7				10				24	36		4		
Lambertia formosa		37	78	31			3															
Lasiopetalum ferrugineum var. *cordatum*						4																
Lasiopetalum ferrugineum var. *ferrugineum*	29	10	7	3	3	1												11				
Lasiopetalum macrophyllum		2																				
Lasiopetalum parviflorum		3	7																			
Lasiopetalum rufum			10																			
Lastreopsis decomposita	14													3								
Laxmannia gracilis		5	7	14	5	39	13	28	3					3			52	61	14	50		

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Legnephora moorei												8										
Leionema dentatum	43	3		2																		
Lemna disperma															50							
Lepidosperma concavum	14	5	5	3																		
Lepidosperma elatius	14										12											
Lepidosperma filiforme		13	10																	4		
Lepidosperma gunnii		2		5		7											8	7				
Lepidosperma laterale	71	71	49	76	62	90	63	6	2	18	38			3		22	56	93	29	23	50	
Lepidosperma urophorum						6														4	100	
Lepidosperma viscidium		5																				
Leptocarpus tenax			2	2																	50	
Leptochloa decipiens													10									
Leptomeria acida		23	10	17		4																
Leptospermum arachnoides		5	22	2																		
Leptospermum continentale																				4		
Leptospermum juniperinum	14																					
Leptospermum morrisonii	43																					
Leptospermum parvifolium			5	14		4														15		
Leptospermum polygalifolium subsp. *polygalifolium*	43	18	10	7	11	4	5							5				7	14	31	50	
Leptospermum trinervium		81	90	73	14	16	3										4	11		54	100	
Lepyrodia muelleri																			43	4		
Lepyrodia scariosa		8	54	12																50	50	
Leucopogon amplexicaulis		2																				
Leucopogon ericoides		10	7	12		1														4		
Leucopogon exolasius		3	5																			
Leucopogon juniperinus		10	2	5	49	47	50	12	7	32	75	15	10	11		22	24	18	14	4		
Leucopogon lanceolatus var. *lanceolatus*		19		3	19	4					25											
Leucopogon microphyllus var. *microphyllus*			29	2																		
Leucopogon muticus			2	3		13														4		
Leucopogon setiger				5		3																
Leucopogon virgatus			2	17																	50	
Lindsaea linearis	14	10	32	17	3	1														8		
Lindsaea microphylla	29	31	32	20	11	7																
Linum marginale							5	3	3								8					
Liparis reflexa	14	2																				

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	35	33	31	32	43	2	1	10	9	15	152	13	14	11	5	12	103	3	4	6	8	34
Lipocarpha microcephala																			14			
Lissanthe sapida				5	11	1																
Lissanthe strigosa		15	24	59	11	34	26	4						3			52	68		42		
Livistona australis					3					14												
Lobelia alata	14													3								
Lobelia gracilis		6	7	5																		
Lobellia dentata		3		3																		
Logania albiflora	29	13		2		1																
Logania pusilla					3	1												4		4		
Lomandra brevis		2	7		5					9												
Lomandra confertifolia subsp. *pallida*						4	11	1	5								4					
Lomandra confertifolia subsp. *rubiginosa*		23		22	5	17	32	3	3								8	4		4		
Lomandra cylindrica		39	44	58	16	3				5							12	4		23		
Lomandra filiformis subsp. *coriacea*		23	15	44	16	34	16	8	2								12	11	14	4		
Lomandra filiformis subsp. *filiformis*		42	32	37	35	24	8	65	34	14				16			68	36	14	19		
Lomandra fluviatilis	29	2		2																		
Lomandra glauca		16	44	7	5	4	3										4	7		31	50	
Lomandra gracilis	29	55	29	10	3	4	8	3	5								12	21		4		
Lomandra longifolia	71	71	12	29	70	37	13	4	5	68	100			57		56	12	39	57	4		
Lomandra multiflora subsp. *multiflora*		53	54	76	57	87	39	55	25		12			8		11	92	71	71	81		
Lomandra obliqua		79	78	95	27	33	5			5												
Lomatia myricoides	100	3														33						
Lomatia silaifolia	14	68	59	46	5	9					12											
Lotus australis								1	2													
Lythrum hyssopifolia									2						50				43			
Macrozamia communis		6																14		4		
Macrozamia spiralis		3		3	3	1											8	7				
Marsdenia flavescens									2			31										
Marsdenia rostrata						1	3				38	31										
Marsdenia suaveolens	14	10						1		5	12											
Marsdenia viridiflora subsp. *viridiflora*								2	2			8										
Marsilea hirsuta															50							
Maundia triglochinoides															50							
Maytenus silvestris		2			11	1		4		55	62			3				7				
Melaleuca deanei			2	2																		

Typical Soil Type:	**Sandstone**				**Sandstone/Shale**			**Shale**						**Alluvium**			**Tertiary alluvium**				**Sand**	**Marine**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Melaleuca decora					3	4	3	20	2					5			64	89	86	58		
Melaleuca erubescens						1	3											7	14	31		
Melaleuca linariifolia	14			2		1		2						19					43			
Melaleuca nodosa			2	3		9		2		9				3			24	82	14	81		
Melaleuca styphelioides							3	3	5	5		77		14	50		4		14			
Melaleuca thymifolia				2		6	3												29	35		
Melia azedarach			2		8			1	2	14	12	15		3		11	4					
Melichrus urceolatus																				4		
Melicope micrococca										9		38										
Mentha diemenica							3	8	5													
Mentha satureioides							5		5		12	8	10	3								
Micrantheum ericoides	14	18	37	10	11	1														4		
Micrantheum hexandrum	29																					
Microlaena stipoides var. *stipoides*	14	37	17	47	86	83	87	92	79	95	25	69	70	97	50	100	100	93	86	69		33
Micromyrtus ciliata																				35		
Micromyrtus minutiflora																				27		
Microtis parviflora					8												4					
Microtis unifolia																	4	4	14	8		
Mirbelia rubiifolia			2	5		1														19		
Mirbelia speciosa subsp. *speciosa*			12	3																		
Mitrasacme polymorpha			20	5	3															23	100	
Monotoca elliptica	14	11	2																	4		
Monotoca ledifolia							3															
Monotoca scoparia	14	27	68	58	5	3												4		4	100	
Morinda jasminoides	29	2			3	3	3			9	50	8		8								
Morus alba										5												
Muellerina eucalyptoides					3						12											
Murdannia graminea								4											14			
Myoporum acuminatum											12											
Myoporum montanum									3				60									
Myriophyllum simulans														3	50							
Myriophyllum variifolium														3								
Notelaea longifolia forma *longifolia*	29	34	2	14	41	31	16	6	3	50	50	77	10	5		22	4	14				
Notelaea ovata										9		8										
Notelaea venosa												15										
Notodanthonia longifolia	14					11	3	1					20			11						
Nymphoides geminata																			14			
Nyssanthes diffusa									2			15	60									

Typical Soil Type:	**Sandstone**				**Sandstone/Shale**			**Shale**						**Alluvium**			**Tertiary alluvium**				**Sand**	**Marine**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Nyssanthes erecta									2			15		3								
Olax stricta		2																			50	
Olearia elliptica						1																
Olearia microphylla		10	5	17	8	17	3										12	43		8		
Olearia tomentosa		2																				
Olearia viscidula						7	24		2			8	50	8								
Omalanthus populifolius										9	12	15						4				
Omalanthus stillingiifolius												8										
Omphacomeria acerba		3	2	3		1																
Opercularia aspera	29	27		5	3	6		3	3		12						4					
Opercularia diphylla		6	10	17	16	54	53	75	25		12			24			96	79	86	73		
Opercularia hispida		2			24		5							3								
Opercularia varia		2		3	22			1										4				
Oplismenus aemulus					14	9	32	14	25	82	50	31	40	95		89	8	4	14			
Oplismenus imbecillis	29	6		2	38	3	24	1	16	41	62	77	10	11								
Oxalis exilis		3			41	7	3	13	2	14				3				7	14			
Oxalis perennans		2		2	8	31	66	53	52	23	50	23	50	57		44	56	29	14	4		
Oxalis radicosa						3	3	2											14			
Oxalis rubens									2													
Ozothamnus diosmifolius		18	15	12	51	63	39	35	2	59	38		10	24			28	68		15		
Pandorea pandorana		27		2	51	1	8	2	15	86	75	85	40	11			4					
Panicum effusum				2	3	3	13	19	18								8		29	23		
Panicum simile		10	5	31	49	79	42	32	15	9			10	8			56	61	43	62		
Parsonsia lanceolata		2								5												
Parsonsia straminea		3		2	3	7	13	1	5	5		23		14	50							
Paspalidium albovillosum						1	5	1					10	3								
Paspalidium aversum								2						5					14			
Paspalidium criniforme								1	3	5		8	20	3		11	8					
Paspalidium distans		2		2	8	40	29	74	33	9				30			44	61	71	35		
Paspalidium gracile						1	3															
Paspalum distichum															50				14			
Paspalum orbiculare						1		1											43			
Passiflora cinnabarina							3															
Passiflora herbertiana subsp. *herbertiana*					3	4	11			41	25	15	10	3								
Patersonia fragilis		2																				
Patersonia glabrata		35	24	29		3																
Patersonia longifolia			2	2	3																	

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Patersonia sericea		24	37	37	3	3												7		50		
Pelargonium inodorum																22	4					
Pellaea falcata		2					3		11			85	40	11								
Pellaea paradoxa								1														
Persicaria decipiens	14							1						14	100							
Persicaria hydropiper														8					14			
Persicaria praetermissa														8								
Persicaria strigosa	14																					
Persicaria subsessilis														3								
Persoonia lanceolata		5	10	8	5	1																
Persoonia laurina		8	2	2	3	1														8		
Persoonia levis	29	82	98	69	14	7	3										8					
Persoonia linearis	29	76	22	69	38	84	42	1		9	50	8		3			16	11		15	50	
Persoonia mollis subsp. *mollis*				3																		
Persoonia mollis subsp. *nectens*						3																
Persoonia nutans																		4		35	100	
Persoonia oblongata						7																
Persoonia pinifolia	14	19	41	14		4				5												
Petrophile pedunculata			5	3																		
Petrophile pulchella	14	2	24	3				1												15	50	
Petrophile sessilis	14	6	54	19																4		
Phebalium diosmeum		2																				
Phebalium squamulosum subsp. *squamulosum*	14	2														33						
Philotheca hispidula				8																		
Philotheca salsolifolia				2														4		8	50	
Philotheca scabra subsp. *scabra*		13	7																			
Philydrum lanuginosum																			14	4		
Phragmites australis														3		11						
Phyllanthus gunnii					3		8	1	3	9	12	15		5		44						
Phyllanthus hirtellus	14	77	80	95	32	53	13										8	32		19		
Phyllanthus similis									3					30		11						
Phyllanthus virgatus								32	23					8		22	8					
Phyllota grandiflora			2																			
Phyllota phylicoides		3	15	2		1																
Pimelea curviflora var. *curviflora*								2														
Pimelea curviflora var. *subglabrata*								4														
Pimelea latifolia subsp. *hirsuta*						1				5												

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Pimelea linifolia subsp. *collina*																				4		
Pimelea linifolia subsp. *linifolia*		31	46	63	35	59	18		2									32		85	100	
Pimelea spicata								2	2			8										
Pittosporum revolutum		5		3	32	3	11	1		73	75	92		5		11						
Pittosporum undulatum	14	27	7	10	84	10				86	75	8						11				
Plantago debilis					3	6	13	24	16	5		31	60	22								
Plantago gaudichaudii								6	8								4					
Plantago hispida							3	1											14			
Plantago varia						1			2													
Platycerium bifurcatum var. *bifurcatum*										5												
Platylobium formosum		2			11					5	50											
Platysace ericoides		13	39	34		7												4		50	100	
Platysace lanceolata		19	10	2	3																	
Platysace linearifolia	29	52	61	20	3															4		
Plectorrhiza tridentata	14																					
Plectranthus graveolens								1					10									
Plectranthus parviflorus					8		8	9	26	27	12	62	60	38		11			14			
Poa affinis	29	15			27	4		1	2	68	62	15		8		44						
Poa labillardieri var. *labillardieri*		8		41	11	37	5	22	38	9		15		3		11	24	18	14	15		
Poa sieberiana var. *sieberiana*		2	2	2	22	6	3	5	8				40									
Podocarpus spinulosus		6																				
Podolobium ilicifolium		8		3	14	6																
Podolobium scandens var. *scandens*				3	3	4		3									4					
Polygala japonica							5	4	7													
Polymeria calycina						6	16	10	3					24			24	4	14			
Polyscias sambucifolia subsp. *A*	14	21		3	49	10	5	2		68	50	8		3		11		14				
Pomaderris discolor	14	6	2	2		4	3															
Pomaderris elliptica subsp. *elliptica*		6		2							12					11	4					
Pomaderris eriocephala							3															
Pomaderris ferruginea	29	6		3		1										11						
Pomaderris intermedia	14	3				3		1			12					11						
Pomaderris lanigera		6		5	5	10																
Pomaderris ligustrina						1																
Pomax umbellata		40	20	76	43	84	42	9	2					3			52	57		46		
Poranthera corymbosa			5																			
Poranthera ericifolia	14	6	17	8																		
Poranthera microphylla		3	2	7	22	34	42	35	23	9				41		56	72	39	71	15		

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Portulaca oleracea									3													
Potamogeton tricarinatus																			14			
Pratia purpurascens		19		14	76	74	76	44	5	64	62	23	30	68	50	56	84	79	86	23		
Pratia surrepens																			14			
Prostanthera scutellarioides																		18		8		
Pseudanthus pimeleoides	14																					
Pseuderanthemum variabile	14	10			46	4	3	3		91	75	69		24								
Pseudognaphalium luteoalbum								1						3								
Psilotum nudum		2																				
Psychotria loniceroides												8										
Pteridium esculentum	43	85	20	12	16	3		1		18	50	8		5		78		4				
Pteris tremula	14											15										
Pterostylis acuminata			2	3																		
Pterostylis concinna			2			9																
Pterostylis erecta		2	2																			
Pterostylis longifolia		5		10	3	1					12											
Pterostylis nutans		3			5																	
Ptilothrix deusta		2	27	15	3	6												4	14	23		
Pultenaea daphnoides		13	2																			
Pultenaea elliptica		6	46	12																54		
Pultenaea ferruginea						1														12		
Pultenaea flexilis	29	24	5	7	3	1																
Pultenaea hispidula		2																				
Pultenaea linophylla		5	5		5																	
Pultenaea microphylla				3		1		8	5													
Pultenaea parviflora																	4	39		8		
Pultenaea retusa		2			3	1														4		
Pultenaea scabra				8	11	1																
Pultenaea stipularis		3	15																			
Pultenaea villifera var. *villifera*																		4				
Pultenaea villosa		2		3	11	7		1		5							20	7	29	8		
Pyrrosia rupestris												23										
Ranunculus inundatus															50							
Ranunculus lappaceus								2														
Ranunculus plebeius									3					3								
Rapanea howittiana												8										
Rapanea variabilis		16		2	14	13	5	2	2	45	50	46	20	5				4				
Rhodamnia rubescens										5												

Typical Soil Type:	**Sandstone**				**Sandstone/Shale**			**Shale**						**Alluvium**			**Tertiary alluvium**				**Sand**	**Marine**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Rhytidosporum procumbens		2	5	2		1												4				
Ricinocarpos pinifolius		24	10	2																4	50	
Ripogonum album												23										
Rorippa laciniata								1														
Rubus molluccanus var. *trilobus*											12											
Rubus parvifolius						1	3	2	18	41	12	46	30	35		22						
Rulingia dasyphylla					3													4				
Rumex brownii								3	11	23	12	23	50	16		33						
Samolus repens																						33
Samolus valerandi														5								
Santalum obtusifolium							5															
Sarcocornia quinqueflora subsp. *quinqueflora*																						67
Sarcomelicope simplicifolia subsp. *simplicifolia*												8										
Sarcopetalum harveyanum	14									32	12	23										
Scaevola aemula							3															
Scaevola albida var. *albida*								2	8				20									
Scaevola ramosissima		3	15	10		1														4		
Schelhammera undulata	14																					
Schizaea bifida		5	15	5																	50	
Schizaea dichotoma			7																			
Schoenus apogon						3	5	6									8	4	100	4		
Schoenus brevifolius		2	2	2																4		
Schoenus ericetorum		2	34	2																		
Schoenus imberbis		3	7	2														4			50	
Schoenus lepidosperma subsp. *pachylepis*	14																					
Schoenus maschalinus					3																	
Schoenus melanostachys	71	13		3		1					12			3								
Schoenus moorei							3													8		
Schoenus paludosus																				4		
Schoenus turbinatus			10																			
Schoenus villosus				2																		
Scleria mackaviensis								3	23			8	20	3								
Scutellaria humilis								5	13			8	10	14								
Scutellaria mollis														3								
Senecio bipinnatisectus		2																				

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Senecio biserratus					3																	
Senecio diaschides						3		2	13					14								
Senecio glomeratus								1	2													
Senecio hispidulus var. *dissectus*		2			3			3									4	4				
Senecio hispidulus var. *hispidulus*					5	4	3	4	15	9		15	30	11		22	8	4	14			33
Senecio lautus		2																				
Senecio linearifolius										5		15										
Senecio minimus						1								5								33
Senecio quadridentatus						1	3	6	10			8	50				12					
Senecio species *E*								1	2													
Sicyos australis												8										
Sida corrugata									39					3								
Sida spinosa								1	5													
Sigesbeckia orientalis subsp. *orientalis*						1	5	4	15	36		62	70	49		44		4				
Smilax australis	14				11					23	38	15										
Smilax glyciphylla	57	77	15	14	8	3	3	1	3	18	50	15		11		33	4					
Solanum aviculare										5												
Solanum brownii										5		8										
Solanum campanulatum								2									4					
Solanum cinereum									2								4					
Solanum opacum	14	2																				
Solanum prinophyllum				2	8	46	76	40	46	59	12	31	60	70		22	20					
Solanum stelligerum										5		38	10									
Solenogyne bellioides								4	2										14			
Solenogyne dominii								3	3													
Sorghum leiocladum								2	11					3			4					
Sphaerolobium vimineum																				4		
Sporobolus creber					3	4	18	17	36				20	5			4		14			
Sporobolus elongatus						3	3	17	21				10	5								
Sporobolus virginicus var. *minor*																						33
Stackhousia monogyna					3		3							3								
Stackhousia muricata							3	2	2								8					
Stackhousia nuda						1		1														
Stackhousia viminea		3	2		3	9	8	47	23	5				3			32	7	14	4		
Stellaria flaccida						1		1	3			54	10	16								
Stenocarpus salignus	57	5										8				22						
Stephania japonica var. *discolor*					3		3		2	14	25	54	10	11		22						

Typical Soil Type:	Sandstone				Sandstone/Shale			Shale						Alluvium			Tertiary alluvium				Sand	Marine
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Sticherus flabellatus	57	3																				
Streblus brunonianus												23										
Stylidium graminifolium	14	15	15	34	5	4												4		69	100	
Stylidium laricifolium		16	2	7																		
Stylidium lineare			15	3																		
Stylidium productum	14	15	2	5																		
Stypandra glauca		8		2	8	30	5					8		3								
Styphelia laeta subsp. *laeta*			2	2		4												11		4		
Styphelia triflora			2	2																		
Styphelia tubiflora			2																			
Styphelia viridis subsp. *viridis*		2		3																		
Suaeda australis																						33
Symplocos thwaitesii												8										
Syncarpia glomulifera		32	2	29	76	27	5	1		77	12	8					4	7				
Telopea speciosissima	14	2	2	2																		
Tetragonia tetragonoides																						33
Tetraria capillaris					3																	
Tetrarrhena juncea		2																				
Tetrarrhena turfosa	14																					
Tetratheca ericifolia			5																			
Tetratheca glandulosa			12																			
Tetratheca neglecta		3	32	3																		
Tetratheca thymifolia		6	2																			
Thelymitra pauciflora					11																	
Themeda australis	14	26	10	68	84	80	76	89	77	23	38	8		22		22	84	54	86	85	50	
Thysanotus juncifolius			2																			
Thysanotus tuberosus subsp. *tuberosus*		2	2	3	3	10	3	1									28	29	14	27		
Todea barbara	43																					
Toona ciliata												8										
Trachymene incisa subsp. *incisa*			5	14	5	6	3											4		8	100	
Trema tomentosa var. *viridis*					3	3		1		36	12	8	20	14								
Tricoryne elatior					3	19	34	43	25					14			52	11	43	15		
Tricoryne simplex		3	5	7		1			2					3						4		
Tricostularia pauciflora			2	2																		
Triglochin microtuberosum															50							
Triglochin procerum	29													3								
Triglochin striatum															50							

Typical Soil Type:	**Sandstone**				**Sandstone/Shale**			**Shale**						**Alluvium**			**Tertiary alluvium**				**Sand**	**Marine**
Map Unit:	**35**	**33**	**31**	**32**	**43**	**2**	**1**	**10**	**9**	**15**	**152**	**13**	**14**	**11**	**5**	**12**	**103**	**3**	**4**	**6**	**8**	**34**
Tristania neriifolia	29	2																				
Tristaniopsis collina										5												
Tristaniopsis laurina	86										12	8		3		11						
Trochocarpa laurina										5												
Tylophora barbata		2			16	3	3	1		55	100	31		8								
Typha orientalis								1							50							
Urtica incisa						1						38		3								
Vernonia cinerea var. *cinerea*				2	16	21	34	46	18	5			10	22		11	52	54	29	15		
Veronica brownii									2													
Veronica calycina	14				3					5												
Veronica plebeia		3			8	41	68	39	23	32		8	20	38		56	28	18	14			
Viola hederacea	29			3						9	25			8		11						
Vittadinia cuneata var. *cuneata*							3	4	3				10									
Vittadinia hispidula var. *hispidula*							3															
Vittadinia pustulata						1	3	3														
Wahlenbergia communis						1	13	4	5				10				8	4		4		
Wahlenbergia gracilis	14	18		14	14	21	24	71	49	18		15	50	49		56	76	36	43	19		
Wahlenbergia luteola						3			5													
Wahlenbergia stricta subsp. *stricta*				5			8	6	11	5							12	7				
Westringia longifolia	29	2				4	5															
Woollsia pungens		11	15	2																		
Wurmbea biglandulosa								1														
Wurmbea dioica subsp. *dioica*								11	2					3			4	11	29			
Xanthorrhoea arborea	29	34		5																		
Xanthorrhoea concava	14	21	37	44	8	13																
Xanthorrhoea media	14	19	56	29	3	1												4				
Xanthorrhoea minor subsp. *minor*		3				6											12	11		77	50	
Xanthorrhoea resinifera		5	17	8																		
Xanthosia pilosa	14	81	44	29	8	6																
Xanthosia tridentata	71	31	32	3		4																
Xylomelum pyriforme		42	15	24		3																
Xyris gracilis			5																			
Zieria cytisoides		2		2			3				12											
Zieria fraseri subsp. *compacta*		2																				
Zieria laevigata		2	2																			
Zieria pilosa	14	8																				
Zieria smithii		3	2		5	3				9	12											
Zornia dyctiocarpa var. *dyctiocarpa*								6	10								8					

Effect of pasture type on regeneration of eucalypts in the woodland zone of south-eastern Australia

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Abstract: Although eucalypt regeneration is an uncommon event in the highly modified rural environments of south-eastern Australia, it still occurs on some roadsides and even in grazed paddocks. A number of observations suggest that under grazing, regeneration is more likely to occur in native pastures than in those dominated by exotics. The apparently adverse effect of exotic pastures was investigated by monitoring growth and survival of eucalypt seedlings — either planted or from sown seed — on the Central Western Slopes of NSW. Survival of seedlings arising from direct drilled seed of *Eucalyptus albens* and/or *Eucalyptus melliodora* in exotic pastures was generally low. However, survival was higher for seedlings emerging in spring (but not at other times) in an annual exotic pasture than for those emerging in spring in a perennial exotic (*Phalaris*) pasture. Experimental plantings of *Eucalyptus melliodora* seedlings adjacent to annual exotics v. a perennial native grass plant showed no significant difference in seedling growth between the two microsites though there was a trend towards enhanced survival near the perennial grass.

Within the context of other work on the regeneration of woodland eucalypts, these results suggest that: (1) competition from annual exotics is a major limitation to the survival of eucalypt seedlings in their first year; (2) competition from a perennial exotic establishing at the same time as the eucalypt seedlings is particularly severe during the eucalypt's second year. In the absence of a major disturbance such as scalping of topsoil, regeneration of eucalypts in exotic pastures is unlikely.

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Introduction

The subhumid zone of southern Australia has been intensively used for many years and modification of the original woodlands and forests ranges from relatively minor to complete. Areas of remnant woodland with intact groundstorey, however, are rare as noted, for example, by Prober and Thiele (1993) in the area originally occupied by grassy *Eucalyptus albens* woodlands. (Botanic nomenclature follows that of Harden (1990–93) and for grasses, Wheeler et al. (2002)). Due to widespread grazing ± cropping, groundstoreys are more appropriately considered as 'pastures': ranging from those still dominated by native perennial grasses ('native pastures') to those dominated by exotic annuals or perennials ('exotic pastures'). Introduction of exotic plants, as well as cultivation and grazing, were considered by Nadolny (1995) to be the main reasons for lack of eucalypt regeneration.

The pre-European settlement frequency and abundance of eucalypt recruitment in woodlands is speculative but was probably dependent on patchy fires and light grazing (Allcock et al. 1999) or canopy disturbance (Yates & Hobbs 1997) followed by suitable rainfall. Observations by Yates and Hobbs (1997) and Allcock et al. (1999) suggest that once woodland modification has reached the stage where the understorey is dominated by exotics, eucalypt recruitment is unlikely. Apart from increased grazing intensity, other changes evident at this level of modification may include soil compaction, nutrient enrichment and reduced litter (Yates & Hobbs 1997, Windsor 2000).

Although natural recruitment is very rare in some areas e.g. the *Eucalyptus salmonophloia* woodlands in the wheatbelt of WA (Yates & Hobbs 1997), it still occurs along some south-eastern Australian roadsides as evidenced by remnant woodlands with mixed age structure (e.g. Schabel & Eldridge 2001). Whether recruitment in these situations is associated with the absence of grazing, intermittent heavy grazing or other disturbance is unclear.

Various authors have noted that eucalypt recruitment is more likely to occur in native rather than exotic pastures e.g. in the mid-north of South Australia (Venning 1985), northern tablelands of NSW (Curtis 1989, 1990) and the central west of NSW (Cluff & Semple 1994, Semple & Koen 2001). Initiation of recruitment in these cases was associated with some form of 'natural' disturbance e.g. light grazing, drought or fire. Recruitment can also occur in exotic pastures but, as noted in most of the documented cases (e.g. Whalley & Curtis 1991, MacLennan et al. 1992, Lawrence et al. 1998), only after a weed-free seedbed has been deliberately or accidentally prepared. This supports Yates and Hobbs' (1997) proposal that the transition from woodlands with exotic understoreys to something resembling their original condition involves a major threshold, which cannot be crossed without considerable intervention.

These observations raise a number of questions. Assuming adequate seed supply and appropriate rainfall, why are native pastures apparently more conducive to eucalypt recruitment; or alternatively, why are exotic pastures not conducive to recruitment? A number of possible reasons have been suggested and some of these are addressed below.

Effects of individual species

In an experiment involving planting a native forb into artificial gaps in two perennial pasture types, Hitchmough et al. (1996) reported that competition from the native pasture (*Austrodanthonia setacea*) was less than from the exotic (*Festuca arundinacea*) one. Also, allelopathic effects may be produced by some species e.g. as reported in residues of the exotic perennial grass, *Phalaris aquatica* (Leigh et al. 1995).

Structure and composition of the pasture

The presence of tussocks themselves may affect eucalypt establishment. Following a fire in an *Eucalyptus pauciflora–Poa* sp. woodland in the Kosciusko area, Noble (1980) reported a significant interaction between the occurrence of two-year old eucalypt seedlings and grass tussocks. Seedlings were rare close to tussocks but most abundant 4–8 cm away. Compared to those in the 4–8 cm zone, seedlings further away tended to be shorter and had more stems. Results were attributed to competition close to the tussock, protection at 4–8 cm and exposure e.g. to frost, further away.

Curtis (1990) observed that burning native pastures produced suitable conditions for eucalypt recruitment but burning exotic pastures did not due to excessive growth of weeds. He also noted that bare ground was usually present between tussocks in native pastures but not in exotic ones where gaps were occupied by annuals. Simulated eucalypt seedfall experiments in exotic annual pastures with variously prepared seedbeds resulted in emergence, even in untreated controls, but survival was low except in the scalped treatment in most seasons (Semple & Koen 1997). Mortalities were attributed to competition from exotic annuals.

Fertility

As many native pastures in the subhumid zone are now restricted to infertile sites, e.g. with skeletal soils, it could be argued that low fertility rather than the presence of native pastures per se, is the issue; or conversely, that enhanced fertility is associated with the presence of exotic pastures and reduced eucalypt recruitment. [However, it should be noted that native pastures and fertile sites are not incompatible. On the NSW tablelands, for example, legumes have been introduced and fertilisers applied to pastures dominated by native grasses (Simpson & Langford 1996) though eucalypt recruitment has not been reported in these situations.] Venning (1985) reported that eucalypt recruitment was uncommon in fertilised paddocks but occurred in adjacent unfertilised ones. Cluff and Semple (1994) reported that eucalypt recruitment, initiated by an earlier fire, was absent from nutrient enriched sites ('sheep camps') within the same paddock.

Windsor (2000) argued that nutrient enrichment and soil compaction limited eucalypt recruitment on grazing lands. As evidence, she cited the success of scalping topsoil (to remove nutrients), followed by harrowing (to reduce compaction) in promoting eucalypt regeneration; but as noted by Lawrence et al. (1998), scalping also removes weed seeds and harrowing could provide safe sites for seeds on the otherwise smooth surface of a scalped soil. Allcock (2002), however, reported poor growth of *Eucalyptus albens* seedlings in the presence of exotic weeds in pot trials, particularly at high levels of phosphorus. Further, it is generally accepted that improving fertility e.g. by applications of fertiliser and/or lime, results in a decrease in woody plants and in increase in herbaceous ones as was as was reported in heathland by Heddle and Specht (1975).

Timing and intensity of grazing

With the exception of fertilised native pastures, most native pastures support lower numbers of livestock than equivalent areas of exotic pastures. Hence, it could be argued that low grazing intensity is responsible for higher eucalypt recruitment; or conversely, that high grazing intensity inhibits recruitment. Although exclusion of livestock and feral animals is generally considered a prerequisite for eucalypt regeneration (e.g. Venning 1988, Anon. 1992), recruitment can occur in native pastures under low grazing intensity (Venning 1985) or under intermittent heavy grazing (Curtis & Wright 1993).

A number of studies have indicated that heavy grazing may promote woody plant regeneration by opening up regeneration niches (Braunack & Walker 1985, Williams & Ashton 1987, Archer 1994) and if woody plants are unpalatable, that continued grazing may favour their survival. Grazing prior to eucalypt emergence, and possibly for some time afterwards (when seedlings are inconspicuous), may benefit eucalypt recruitment initially by creating bare ground and subsequently by removing annuals, which are generally grazed preferentially, at least by sheep (Wilson & Harrington 1984). More advanced seedlings, however, are preferentially browsed by some native and feral animals (Leigh & Holgate 1979, McIlroy 1984) as well as by domestic stock, at least during some periods of the year (Semple & Koen 2001). Some studies of fenced v. unfenced eucalypt seedlings have shown no differences in mortality, e.g. in *Eucalyptus incrassata* (Wellington & Noble 1985) and *Eucalyptus marginata* (Stoneman et al. 1994), where mortality was attributed primarily to water deficits and/or high summer temperatures. Other studies, however, have shown increased survival in exclosures, particularly after fire in the case of advanced ('lignotuberous') seedlings of *Eucalyptus pauciflora* (Leigh & Holgate 1979).

Deliberate attempts at initiating recruitment in woodlands by excluding livestock have generally been unsuccessful even when weed control was attempted. Exclosure and weed control around seven eucalypt trees of different species in SA resulted in recruitment in only one species, *Eucalyptus camaldulensis* (Venning 1988), though pasture type was not specified. A similar lack of response to exclosure and one application of herbicide occurred at two woodland sites with exotic pastures in the Bathurst area in the late 1980s (Semple, unpublished data). However, as noted previously, exclosure and particular attention to seedbed preparation in exotic pastures can result in recruitment in some years.

Despite these reservations, fencing native vegetation is a common conservation practice. Facilitating eucalypt recruitment may not be the primary aim of fencing but it is often assumed that it will occur. Spooner et al. (2002) investigated this hypothesis by comparing tree regeneration in areas that had been fenced for 2 to 4 years with adjacent unfenced areas in three native woodland types (two eucalypt and one pine) of southern NSW. Across the 47 paired sites, they found significantly more regeneration in the fenced areas. As sites were initially selected for fencing on the basis of 'relatively high quality', it can reasonably be assumed that ground-storeys were dominated by native grasses i.e. 'native pastures'. The authors claimed to be assessing post-fencing recruitment but its definition viz. saplings less than 3 m tall, suggests that this may not always have been the case. To achieve this height, growth rates would have to have been up to 75 cm/year (for 4 years of exclosure) or 150 cm/year (for 2 years of exclosure). Even the lower of these growth rates is comparable only to rates achieved from very successful cases of direct seeding (e.g. Semple and Koen 2001 Table 3) not what would be expected in the presence of uncontrolled herbaceous competition. It is therefore likely that some, and perhaps all, of the regeneration assessed was pre-fencing suppressed ('lignotuberous') seedlings/saplings rather than post-fencing recruitment.

This brief review supports the general notion that eucalypt recruitment is more likely to occur in native pastures than in exotic ones. However, the reasons for this are still unclear as factors such as fertility and grazing regime may interact with pasture composition/structure. Further, as noted by Venning (1988), recruitment processes may also differ between eucalypt species themselves.

In an attempt to shed some light on factors affecting recruitment in non-native pastures, three eucalypt seeding/planting experiments were carried out on in the Central Western Slopes botanic region in the late 1990s. Seedlings of local eucalypt species, *Eucalyptus melliodora* and/or *Eucalyptus albens*, were established either in situ from seed (direct seeding) or from tubestock, in seedbeds prepared by mowing and/or one or more applications of herbicide. Prior to sowing/planting, all sites were fenced to eliminate grazing by domestic and feral animals as a factor affecting seedling survival. Although these experiments did not involve natural recruitment, it was assumed that factors affecting growth and survival of eucalypt seedlings, whether naturally or artificially regenerated, would be similar.

Specific hypotheses being tested were: (1) Eucalypts can be established from seed in pastures dominated by the competitive exotic perennial, *Phalaris aquatica*, if it can be controlled during the critical first year of the eucalypt's life; (2) Spring is the optimal sowing time for eucalypt establishment in annual exotic pastures; (3) Survival/growth of eucalypt seedlings is higher when they are planted adjacent to a native grass than when planted within annual exotics.

Methods

Experiment A: Success of direct drilled eucalypt seed in a Phalaris*-dominant pasture treated with herbicide up to one year previously*

The experimental site at Walli (33° 40' 00" S, 148° 53' 20" E, 600 m a.s.l) was located on a low rise in an area originally supporting *Eucalyptus albens*. The site had been grazed for many years and fertility had been enhanced by applications of phosphate. *Phalaris aquatica*, *Trifolium* spp. and other exotic annuals dominated the pasture. Five seedbeds (treatments) were prepared using a single application of the non-selective herbicide glyphosate (15 mL/L water, applied with a knapsack) at either 12 months (September 1995), 10 months (November 1995), 6 months (March 1996), 3 months (June 1996) or 0 months prior to sowing. The area was mown regularly to simulate close grazing during this period. Glyphosate was also applied twice to all treatments in the two weeks prior to sowing in September 1996. (It was hoped that the duration of weed control achieved post-sowing would be directly proportional to the duration of weed control effort applied pre-sowing.) The five treatments were replicated five times as blocks.

Seed of *Eucalyptus albens* was sown in shallow furrows prepared with a small pick at the rate of 1 g (seed + chaff)/ 1.5 m row in four rows within each 2 m × 2 m plot. Seed was covered by a few millimetres of soil and pressed down by hand. Germination testing under a daily 20°C dark/ 30°C light regime for one month, indicated 256 live seeds/g (seed + chaff). Herbaceous vegetative cover of each plot was assessed by two throws of a 2 m × 0.5 m 100-point quadrat at regular intervals until May 1997. Eucalypt seedlings were counted in each row at regular intervals until May 1997 then less frequently until early February 1999.

Seedling counts and vegetative cover data were analysed using analysis of variance (ANOVA) methods (Genstat 5 Committee 1995). The repeated measures nature of the eucalypt seedling counts was addressed by analysing data at strategic time points, namely at the first time of observation and at the end of the summer seasons.

Experiment B: Success of direct drilled eucalypt seed sown monthly in an exotic annual pasture

The experimental site at Manildra (33° 10' 40" S, 148° 42' 50" E, 460 m a.s.l.) was located on a mid-slope with scattered *Eucalyptus albens*, *Eucalyptus melliodora* and *Eucalyptus microcarpa*. The site had been grazed for many years and fertility had been enhanced by occasional applications of phosphate. The pasture was dominated by exotic annuals with scattered perennial native grasses, especially *Bothriochloa decipiens*. Six months prior to the sowing trial described below, much of the biomass and scattered perennials were removed by mowing and applying glyphosate at 15 mL/L water using a knapsack.

The experiment comprised twelve treatments of monthly sowings, replicated three times as blocks. Each 3 m × 0.6 m plot was split into two 3 m long rows, which were randomly allocated to 1.5 g (seed + chaff) of either *Eucalyptus albens* or *Eucalyptus melliodora*. Germination testing under a daily 20° C dark/30° C light regime for one month, indicated 170 and 736 live seeds/g (seed + chaff) of *Eucalyptus albens* and *Eucalyptus melliodora* respectively.

Seedbed preparation was similar to the 'minimalist' treatment in Experiment A. Plots were mown at regular intervals to simulate grazing until two weeks before sowing when glyphosate was applied to the three replicate plots to be sown next. Adjacent plots were protected from the herbicide by plastic sheeting. Glyphosate was reapplied in the morning of the day of sowing. Shallow rows were prepared with a small pick, seed was evenly distributed and covered with a few millimetres of soil, which was pressed down by hand. Seed was sown in the first week of every month from June 1996 to May 1997. Seedlings were counted monthly for 12 months and, to assess long-term survival, again in early 1999 and mid– 2000. Plant heights were also measured at the last observation.

Survival data were reduced from the 2 species × 12 months-of-sowing treatment dimension by aggregating species and pairing consecutive months of sowing. Since maximum germinations varied noticeably between month-of-sowing pairs (8.7 to 30.2 seedlings/m), and given that interest was in relative survival rate rather than absolute survival numbers, data were expressed in units of percent survival (as a proportion of maximum germination). Results were summarised graphically by presenting average survival percentages, with variances of means indicated by s.e.m. error bars for only the combination (August/September 1996) so as to not clutter the graphic. Statistical analysis was not attempted due to the data exhibiting created means (forced 100% values), differing treatments at any one time point, and many zeros, especially at the later sowing times.

Experiment C: Growth and survival of eucalypt seedlings planted adjacent to native and exotic Plants

This experiment was carried out at the same site as Experiment B. Seedlings (*c.* 6 months old) of *Eucalyptus melliodora* were planted in paired microsites within the pasture after it had been mown to a height of *c.* 4 cm: (a) adjacent to a *Bothriochloa decipiens* plant and (b) within emerging or existing annual exotics. Seedlings were planted with as little disturbance to the soil and existing plants as was practicable. Plantings took place in May and September 1998 and, with some modifications, in April and September 1999. For the latter plantings, all extraneous perennials were removed prior to planting as follows. Native perennial grass microsites (i.e. *Bothriochloa decipiens* plants) were identified in March 1999, protected with an inverted bucket, and the area within a 1 m circle centred on the bucket sprayed with high concentration (20 mL/L water) glyphosate. Eucalypt seedlings were subsequently planted in pairs, the first adjacent to the *Bothriochloa decipiens* plant and the other *c.* 30 cm away in exotic annuals, in April and September 1999.

Forty to eighty seedlings were planted on each occasion. They were given a liberal application of water at planting and subsequently if considered necessary (Table 1). Following an acclimatisation period (when any pairs with one or more dead seedlings were excluded from further evaluation), seedling heights were measured from ground surface to uppermost green leaf at regular intervals for up to 12 months.

For each the four plantings, the statistical analysis considered pairs of seedlings as blocks and the two microsites as treatments in a randomised blocks design. Seedling height, change in seedling height between successive observations, and height change over the entire season for surviving seedlings were analysed using this framework as an unbalanced general linear model when one or both of the pair had died. Due to many seedling deaths during the series of experiments, some times of observation were not analysable due to lack of data. Although the pattern of seedling death in both microsites and in all plantings was similar, any differences in survival percentages at the final times of observation were analysed using generalised linear models.

Table 1. Conditions for *Eucalyptus melliodora* seedlings planted at Manildra in autumn and spring of 1988 and 1999.

	May 98	**Sept. 98**	**April 99**	**Sept. 99**
Seedbed preparation	Mowing prior to planting		Removal of extraneous perennial grasses with glyphosate in March 1999 & mowing prior to planting	
No. of seedling pairs planted	40	21	25	26
No. of follow-up irrigations	0	2	4	1
No. of seedling pairs after acclimatisation	32	18	8	25

Results

Experiment A: Success of direct drilled eucalypt seed in a Phalaris-*dominant pasture treated with herbicide up to one year previously*

Rainfall (Figure 1) was above average during germination and early establishment but was below average in the following autumn, winter and spring. However, during the second year (summer 1997/98 to spring 1998), rainfall was generally above average.

The proportion of live seed sown that produced seedlings at the time of maximum emergence was relatively low (2.2–6.4%). Levels of bare ground at emergence increased with the length of pre-sowing period of *Phalaris* control (r=0.9, n=5, P=0.04) but this did not affect numbers of emergents (Table 2).

Weeds, including young *Phalaris*, rapidly recolonised the plots and $1^{1}/_{2}$ months after emergence, mean live herbaceous ('weed') cover in the treatments ranged from 45–65%. Seven months after eucalypt emergence, *Phalaris* was evident in all treatments, particularly those with the shortest period between initial spraying and sowing. At the last observation, $2^{1}/_{4}$ years after emergence, *Phalaris* was dominant in all treatments.

Seedling numbers declined in the first summer then stabilised until a crash in the population occurred in the second summer. Nett survival (i.e. seedling numbers at maximum emergence–deaths + delayed emergents) rates were similar in all treatments (Figure 2). The maximum total number of seedlings recorded across all replicates during the period of emergence (including those which emerged late) at the experimental site was 935. At one year of age, seedling numbers had declined to 213, a survival rate of 23% and of these only 34 (16%) survived the second summer, despite above average rainfall. By the last observation, at $2^{1}/_{4}$ years of age, only 17 contorted seedlings were present within the *Phalaris* stand.

Table 2. Herbaceous vegetative cover and numbers of eucalypts at Walli at emergence in October 1996.

Treatment: no. months between first herbicide application & sowing	Mean live cover (%)	Mean bare ground (%)	Mean no. of emergents/m
12	0.2	37.5	6.5
10	0.0	22.2	5.4
6	1.0	15.3	4.0
3	4.8	15.9	3.7
0	1.9	9.3	10.9
s.e.d.	0.9*	3.3	2.5

*calculated by excluding the mean with 0% live cover

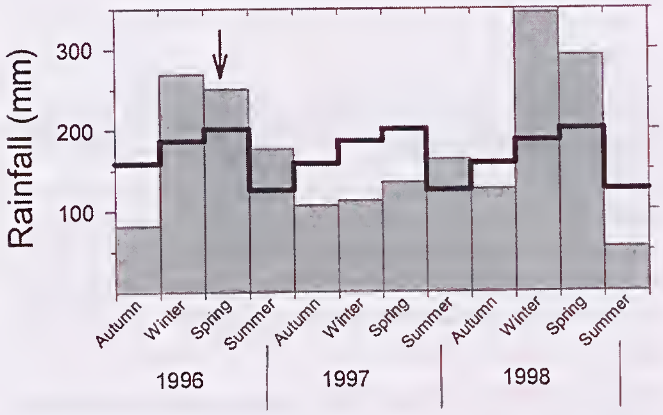

Fig. 1. Seasonal rainfall at 'Kentucky' (Bureau of Meteorology station no. 63234) during the eucalypt direct drilling experiment at Walli. Sowing time indicated by the arrow. The thickened line represents seasonal means.

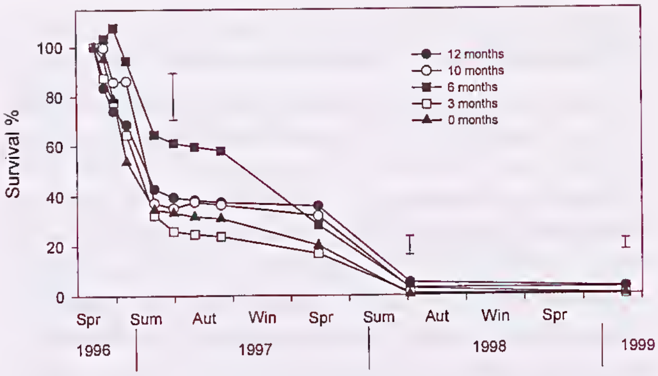

Fig. 2. Percentage nett survival of *Eucalyptus albens* seedlings in a re-establishing *Phalaris* pasture at Walli following direct drilling on 27 September 1996 into seedbeds prepared with one application of glyphosate at 12, 10, 6, 3 or 0 months prior to (and two applications just before) sowing. Reference datum is the average plant counts at the first observation on 28 October 1996 (see Table 2). Error bars are LSDs (P=0.05).

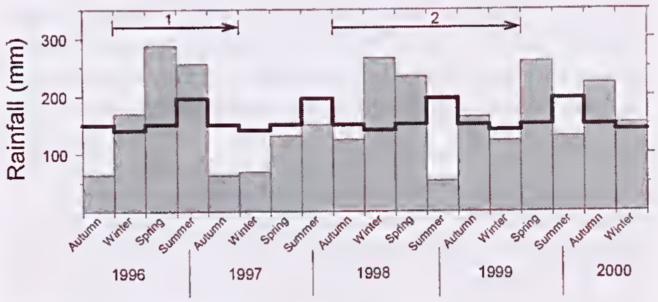

Fig. 3. Seasonal rainfall recorded at Manildra P.O. during the period of the eucalypt sowing and planting experiments. Thickened line represents long term seasonal means. Periods of monthly sowing of eucalypt seed, and of planting seedlings near exotic and native plants are represented by horizontal arrows 1 and 2 respectively.

Experiment B: Success of direct drilled eucalypt seed sown monthly in an exotic annual pasture

Rainfall was above average during the first nine sowings but was below average during the last three (autumn 1997) and in the subsequent winter (Figure 3). All sowings yielded seedlings. Maximum numbers ('maximum emergence', Figure 4 legend) were usually recorded one to two months after sowing except in March and April 1997 when there was insufficient rainfall for germination until May. In the latter case, seedlings emerged at the same time as those in the May sowing. Averaged across all sowings, the proportion of seedlings at maximum emergence was 10.1% (*Eucalyptus albens*) and 4.5% (*Eucalyptus melliodora*) of seed sown. Seed sown in December 1996 and February 1997 yielded the lowest proportions of emergents. Delayed emergence i.e. after maximum emergence, occurred following a number of sowings but numbers were generally low and were not included in the above calculations.

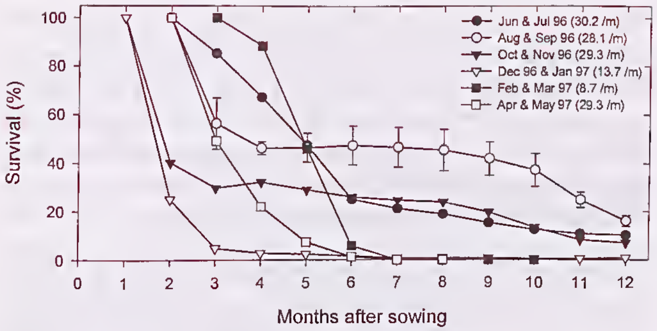

Fig. 4. Percentage nett survival of *E. albens* and *E. melliodora* seedlings in an exotic annual pasture at Manildra following direct drilling each month, June 1996 to May 1997, into seedbeds prepared with glyphosate. Sowing months have been amalgamated as pairs. Maximum seedling counts per month-pair shown in legend. Error bars are s.e.m.

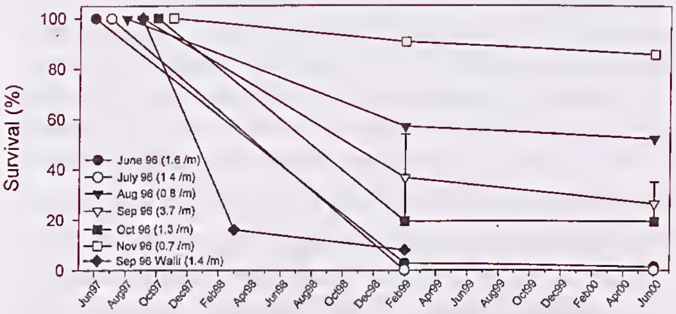

Fig. 5. Survival of one year old eucalypt seedlings from (a) sowings in different months in an exotic annual pasture at Manildra and (b) from the September 1996 sowing (aggregated across all treatments) in a re-establishing phalaris pasture at Walli. Maximum average seedling counts shown in legend. Error bars are s.e.m.

Virtually all seedlings from the summer and autumn (December 1996–May 1997) sowings were dead after one year (Figure 4), possibly reflecting below average rainfall following these sowings. Seedlings from the August/September 1996 period maintained the highest rate of survival during the first year of growth.

Figure 5 focuses on the survival of these seedlings once they reached one year of age. With one exception (a single survivor from the June 1996 sowing), all survivors present at June 2000 were from the August to November 1996 sowings. For comparison purposes, survival of one year old seedlings from the September 1996 sowing at Walli (experiment B) has been included in Figure 5. Although a critical measurement (late summer–early autumn 1998) is missing from the Manildra data, it appeared that the population crash in the second summer in the Walli *Phalaris* pasture, was less evident in the exotic annual pasture at Manildra, particularly for the August, September and November 1996 sowings.

At June 2000 the mean height of survivors from the August to November 1996 sowings was 89.6 cm, an average growth rate over c. 3½ years of 25.6 cm/year.

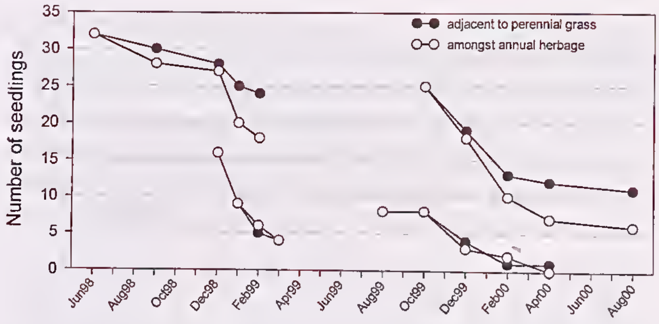

Fig. 6. Survival of acclimatised *E. melliodora* seedlings after plantings in two microsites at Manildra in autumn and spring of 1998 and 1999.

Experiment C: Growth and survival of eucalypt seedlings adjacent to native and exotic plants

With the exception of two dry summers, seasonal rainfalls were near or above average between planting and final measurements in August 2000 (Figure 4). However, rainfall from mid-autumn to early winter in 1999 was low and despite a number of follow-up irrigations, most of the original 50 seedlings planted in autumn 1999 died during the acclimatisation period (Table 1). Though many seedlings died during the dry summers, deaths were recorded in all seasons (Figure 6). Survival rates were low, particularly in the last three plantings (Table 3). The height of the pasture exceeded that of the eucalypt seedlings for much of the time, particularly in spring.

Growth rates of survivors ranged from c. 6 to 23 cm/y (Table 3). There were no significant differences in growth rates between seedlings adjacent to *Bothriochloa decipiens* and those amongst annual exotics during or at the end of the observation period in any of the plantings. However, for the autumn 1998 and spring 1999 plantings, final survival percentages were significantly ($P < 0.05$) lower for seedlings planted amongst annual exotics than for those adjacent to the native perennial grass.

Table 3. Growth and survival of eucalypt seedlings after plantings at Manildra in autumn and spring of 1998 and 1999. P = adjacent to a native perennial grass; A = amongst annual herbage.

	Autumn 98		Spring 98		Autumn 99		Spring 99	
	P	A	P	A	P	A	P	A
Survival (%)	75	56**	22	22	12	0	44	24**
Growth (cm/y)*	5.9	8.3	23.3	22.5	insufficient data		21.2	16.0

* Mean height increase of survivors from the end of the acclimatisation until the final observation (periods ranging from 4–10 months) expressed on an annual basis.

**Significant difference between microsites.

Discussion

Following successful emergence, eucalypt seedlings are subject to a range of hazards including herbivory, pathogens, competition from other plants and adverse climatic conditions.

These are inter-related as rainfall regime not only affects eucalypt seedlings directly but also indirectly through its effects on the abundance of herbivores and other plants. The latter factors can be manipulated to some extent e.g. by removing domestic herbivores and herbaceous competition at critical times to enhance regeneration (Whalley & Curtis 1991, Semple & Koen 1997, Lawrence et al. 1998).

If as data cited by Florence (1996, chapter 4) suggests, much of the eucalypt seedling's early growth in subhumid environments is allocated to root production, then seedlings are likely to be particularly susceptible to competition from plants which allocate more resources to top growth e.g. annual 'weeds'. Though this strategy may result in high losses of eucalypts, there is some evidence suggesting that once the eucalypt seedling is about one year old, its chance of survival is high. A number of observers (e.g. Curtis 1990, Dalton 1993, Colquhoun 2000) have reported that herbaceous competition affects survival during the eucalypt's first growing season; but in subsequent years it primarily affects growth.

Whether any one of the conditions affecting successful regeneration can be rated 'more important' than the others is doubtful as failure to satisfy any one condition at an appropriate time can lead to regeneration failure. In the experiments reported in this paper, conditions of seed supply, seed/soil contact and absence of large herbivores (and in the case of the planted seedlings, moisture supply during early growth) were satisfied. Climate and post-sowing herbaceous competition were not controlled though aspects of the composition of the latter were.

Most of the initial hypotheses were rejected:

1. Eucalypts could not be successfully established in a *Phalaris* pasture even where chemical control commenced one year before sowing. Levels of bare ground and live herbaceous cover were apparently favourable at eucalypt emergence; and survival of seedlings after one year (23%) was within expectations. However, only 8% of these survived to an age of 52 months, a much lower rate than was expected.
2. Survival of eucalypt seedlings after one year in a pasture dominated by annual exotics was highest following sowings in the months of June to November. After a further year, however, virtually all of the seedlings from the June and July sowings were dead. Though this tended to support the hypothesis that sowing in spring (August to November in this case) was the optimal sowing time for long-term survival, below-average rainfall following the summer and autumn sowings may have disadvantaged seedlings that emerged during this time.
3. There was no difference in the rate of growth between eucalypt seedlings planted beside a native perennial grass (*Bothriochloa decipiens*) and those planted within annual exotics. However, survival rate was enhanced by the perennial grass (or reduced by the exotics) in two of the four plantings.

The sowing experiments suggested that exotic pastures, whether dominated by annuals and/or perennials, were disadvantageous to the survival of young eucalypts. This is supported by previous experiments (e.g. Semple & Koen 1997, Lawrence et al. 1998) that showed that when exotic herbage competition was kept low for some time e.g. by scalping topsoil, eucalypt survival was enhanced.

Although there is some evidence that native pastures may be 'protective' of eucalypt seedlings (e.g. as reported by Noble 1980), this was a 'mechanical' effect that conceivably could also occur with tussocks of exotic grasses. Other evidence (e.g. Hitchmough et al. 1996) suggests that native grasses may be 'less competitive' than exotic pastures and this may have been the explanation for the high survival rate of one-year-old naturally-recruited seedlings in a native *Themeda* pasture reported by Semple and Koen (2001). This pasture was subjected to nil or infrequent 'crash grazing' and all eucalypt deaths were attributed to damage by sheep. Survival was high (91%) but mean growth rate from presumed time of emergence was low at 16.6 cm/y and attributed to pasture competition and harsh winters at an elevation of 860 m a.s.l. By contrast, eucalypts had low survival rates in the exotic annual pasture at Manildra but survivors achieved a mean growth rate of 25.6 cm/y from emergence to c. $3^1/4$ years old.

The results of experiment C suggest that the single native grass plant may have conferred some benefit to eucalypt survival, though not growth. However, *Bothriochloa decipiens* was not dominant at the experimental site and consequently did not suppress cool-season annuals as was reported in *Bothriochloa*-dominant pastures by Moodie (1934) and in roadside eucalypt plantings by Colquhoun (2000). Planting eucalypt seedlings within a sward, rather than adjacent to just one plant of *Bothriochloa decipiens* may have yielded a more clear-cut result.

The exotic v. native status of the dominant pasture grasses is probably not the real issue; rather it is what occupies the spaces between the tussocks. In the highly modified woodland belt of south-eastern Australia, exotic annuals are abundant and, as noted by Prober (1996), they become more abundant towards the south. Though annuals compete for nutrients and moisture, their main effect on very young eucalypts is probably for light: 'smothering' by broad-leaved annuals (e.g. *Echium* and *Trifolium* spp.) during early growth and later on, by the collapse of erect grasses (e.g. *Lolium* and *Bromus* spp.) in late spring and early summer.

Although some eucalypts may escape this competition, it would be expected that those which emerged after cool-season annuals had died viz. in late spring or early summer, would have a higher chance of survival, albeit under hotter and drier conditions during early establishment. Limited support for this is provided by the time of sowing experiment and from documented cases of successful eucalypt regeneration following emergence in late spring and summer (Lawrence et al. 1998 Table 4).

If seedlings of an exotic perennial such as *Phalaris* are also present during the eucalypt's first year, it appears that the effect is little different to that of annuals: compare survival in the re-establishing *Phalaris* (and exotic annual) pasture in Figure 2 with that of the spring-sown eucalypts in the exotic annual pasture shown in Figure 4. Data from Figure 5 suggest that survival of the one year old seedlings from the spring 1996 sowing in the re-establishing *Phalaris* pasture was much lower than in the annual pasture. The presence of newly-established *Phalaris* plants at Walli was probably responsible for the sharp decline in numbers during summer 1997/98.

As far as eucalypt regeneration is concerned, the main difference between exotic and native pastures is probably the low levels or poor growth of exotic annuals in the latter. This in turn is probably related to soil fertility, either natural or induced e.g. by 'pasture improvement' or nutrient concentration by livestock. Landsberg et al. (1990) found significantly higher levels of available nitrogen in soils of grazed woodlands than in matched but essentially ungrazed stands with intact under-storey. Prober et al.'s (2002) study of intact and degraded under-storeys of grassy box woodlands found a strong association between soil nitrate and the dominance of robust exotics.

Grazing too is an important factor in eucalypt regeneration but its effects appear to be interactive with a range of factors such as fire, climatic conditions, spatial variation in nutrients (Clarke 2000) and pasture composition. Effects can be beneficial to emergence and early survival e.g. by selective removal of or prevention of seeding by annuals and/or creating bare ground. Young eucalypts can be killed by herbivores but at least some may survive in lightly grazed or crash-grazed native pastures.

It follows from these tentative suggestions that eucalypt regeneration is unlikely to occur where exotic perennials or annuals are abundant in the pasture. In the former case, scalping to remove existing plants and seed, or control by non-selective herbicides for a period in excess of one year, appears to be necessary. Residual herbicides such as simazine may also have a role, at least in the area adjacent to the eucalypts (Dalton 1993, Semple et al. 1995). These techniques are unlikely to be practical except over small areas such as strips, which are to be direct seeded or planted with tubestock.

Where annuals dominate or are abundant (e.g. in a native pasture), a number of possibilities present themselves: (1) preventing seeding by strategic crash-grazing or 'spray topping' (e.g. Burton 2002) in the year prior to seeding with eucalypts, (2) adopting normal agronomic procedures for growing a cereal crop; or in areas with particularly high fertility (3) depleting nutrients (and hence, subsequent growth of annuals) by growing and harvesting/grazing a high nutrient requirement crop such as sorghum.

In those native pastures where annuals contribute little to groundcover, all that may be necessary is the creation of bare ground by crash-grazing or burning prior to eucalypt seeding. The corollary to this is that in areas of native pasture where eucalypt regeneration is not required e.g. in pastoral areas of the *Eucalyptus populnea – Callitris glaucophylla* semi-arid woodlands, supplying seed of annuals (e.g. commercial varieties of *Trifolium* or *Medicago* species) and fertilisers may reduce the likelihood of eucalypt regeneration.

Conclusions

The results from the field studies described above and other work suggest that a major limitation to eucalypt regeneration in the woodland belt is the presence of exotic species in the pastures/ground-storeys of this highly modified region. In situations where annual exotics (or re-establishing exotic perennials) are abundant and actively growing, the effects of seedbeds prepared by knockdown herbicides, burning, slashing and/or grazing are short-lived. Competition for light and probably moisture by the herbaceous plants appears to be the main reason for low eucalypt survival during the first growing season. Eucalypt survival rates are generally higher in the second growing season except where newly-established exotic perennials (e.g. *Phalaris*) are present in which case survival would be expected to be very low.

The adverse effects of exotic annuals (predominantly cool-season types in southern areas) are ameliorated in low fertility situations and in relatively intact native pastures where they are less common. Where annuals are abundant, the young eucalypt can 'escape' their effects by emerging after they have 'hayed off' or following their removal (e.g. by herbicides) late in their growing season.

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Changes in dune vegetation over 60 years in a sand-mined area of the NSW lower North Coast

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Abstract: Sand mining has been responsible for much of the degradation of the indigenous flora of sand dunes in New South Wales, to the extent that authentic foredune plant communities are now uncommon in much of NSW and southern Queensland. Dune heaths are very susceptible to invasion and infestation by the weed, bitou bush (*Chrysanthemoides monilifera* subsp. *rotunda*). This paper compares the floristic composition of dunes in 1941 (before sand mining) and 1997 & 1999 (after sand mining and invasion by bitou bush), at Bennetts Beach, Hawks Nest, on the lower north coast of NSW. The 1941 data provide a unique example of authentic foredune vegetation and is the first quantitative analysis of coastal dune vegetation in NSW. In 1941, 25 native species were recorded in the 0.5 ha site. Nine of these were considered to be characteristic of dune communities and eight of these nine were also recorded in a 1939 survey at Myall Lakes. Four other studies in the intervening 60 years contain species lists of dune vegetation in this general area (1986, 1995, 1997 and 1999). Of a total of 17 species considered to be strongly associated with dune habitats, five were reported in all of six surveys and 15 occurred in one or more of the more recent surveys (1986 and later); the two exceptions were *Austrofestuca littoralis* and *Senecio spathulatus*. Only one introduced weed was recorded in 1941 (*Cakile edentula*) and the only weeds recorded in 1939 were *Cakile edentula* and *Oxalis corniculata*, both cosmopolitan species. Thirteen additional weed species, the most abundant being *Chrysanthemoides monilifera*, were recorded in the more recent surveys. A set of 14 native species that are more typical of heath and eucalypt forest and woodland communities than of the dunes were absent in the 1939 and 1941 surveys but occurred in one or more of the post-mining surveys of 1995, 1997 and 1999. Detailed plant distribution and abundance were assessed in the same part of Bennetts Beach in 1941, 1997 and 1999. All show some patterns of zonation across the sand dune. However, clear phytosociological patterns of the dominant species that were obvious in 1941 were lacking in the 1997 and 1999 analyses. These contrasts suggest that post-mining revegetation has resulted in weed invasion, addition of native species from other communities, and a disruption of the distributions of typical dune species of species across the sand dunes that has been only partially recovered since sand mining and invasion of bitou bush.

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Introduction

In Bentham's *Flora Australiensis* (1866), descriptions of plants found on coastal sand dunes of New South Wales are attributed to collections made by the early explorers. More than a century later, the first publications on the sand dune vegetation of NSW came solely from work on the 'central coast' (Hamilton 1918; Osborn & Robertson 1939; Pidgeon 1940; Davis 1941), now referred to as the 'lower north coast'. There are now many reports on coastal dune vegetation in NSW (see the annotated bibliography by Clarke 1989a; also Carolin & Clarke 1991, Buckney & Morrison 1992, Clarke 1994). Clarke and Chapman (1989) argued that '...basic understanding of the distribution and abundance of coastal sand dune species and vegetation types was inadequate ... for support of informed management of dune vegetation.' The reports by Clarke (1989a,b), Clarke & Chapman (1989) and Chapman (1989) now provide a more comprehensive description of the current state of dune vegetation. Unfortunately, the indigenous dune floras of the central and north coasts of NSW have been altered considerably during the past 80 years or more, so that authentic foredune plant communities are no longer common (Chapman 1989).

Although users of the foredune environment, including off-road recreational vehicles, have caused disturbance to the indigenous flora, sand mining has been the most destructive. From as early as 1934, heavy mineral sands (e.g. rutile, zircon, ilmenite, monazite) have been mined along 1700 km of the eastern coastline of Australia, from Gladstone (Qld) to Port Kembla (NSW) (Allen et al. 1990). On the lower-north and north coasts of NSW, sand mining has occurred on beaches, foredunes and hind dunes. Mining companies are now required to rehabilitate these areas, including revegetation with native species (Fox & Fox 1978, 1984, Allen et al. 1990). The revegetated areas are particularly susceptible to invasion and infestation by bitou bush (*Chrysanthemoides monilifera* subsp. *rotunda* (DC) Norlindh). This plant was introduced from South Africa over 100 years ago (Chapman 1989, Parsons & Cuthbertson 1992) and, in the late 1940s, was identified as suitable for arresting sand drift after successfully colonising extensive mobile dunes north of Newcastle. Bitou bush spread rapidly north of Sydney to the sand islands of SE Queensland, and its successful competition with indigenous species led to the withdrawal in 1971 of the official support for its use in sand stabilization (Cooney et al. 1982).

This paper reports detailed studies of species composition and zonation, nearly 60 years apart (1941 and 1997 & 1999), in foredune vegetation at Bennetts Beach, Hawks Nest, on the lower north coast of NSW. Along with surveys in nearby areas, conducted in 1939 (Osborn & Robertson 1939), 1986 (Myerscough & Carolin 1986) and 1995 (Kohler et al. 1995), they provide an opportunity to compare the current vegetation of mined, bitou-infested dunes with the 'authentic' dune plant community that existed in the 1940s. This paper has the following aims:

1. To place on record the first quantitative analysis (by Pidgeon 1942) of authentic foredune vegetation in NSW.
2. To compare this community, as it existed before sand mining and invasion of bitou bush, with the floristic composition, abundance of species and current status of the mined and revegetated dunes in the same area in the late 1990s.

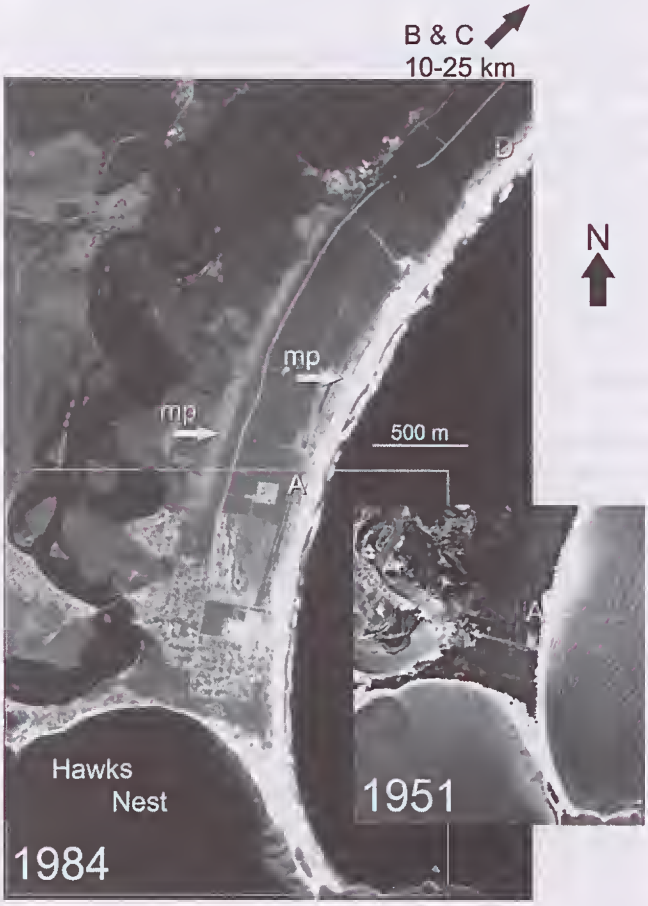

Fig. 1. 1984 aerial photograph showing the township of Hawks Nest, at the southern end of Bennett's Beach (Port Stephens 9332, 1984, B&W 1:40 000 NSW 3389, Run 3, Print 100). The inset shows the southern portion of the beach as it appeared in 1951, prior to sand mining (Port Stephens 9332, 1951, B &W 1:30 000 SYV1294, Run 4, Print 5093). The study areas referred to in the Methods are indicated on the 1984 photo. The sand mining paths are indicated as 'mp'. (Source of photos: © Land and Property Information, Panorama Ave., Bathurst, www.lpi.nsw.gov.au). The label 'A' in the 1951 inset indicates the location of the 1941 study and, in the 1984 photograph, indicates the location of the 1997 and 1999 studies. 'D' indicates the location of the herbicide study by Kohler et al. (1995). The broader surveys by Osborn & Robertson (1939) ('B'), Myerscough & Carolin (1986) ('C') were approximately 10–25 km north of the northern edge of this photograph, within Myall Lakes National Park.

Study area

Bennetts Beach, on the northern shoreline of the entrance to Port Stephens, 250 km north of Sydney, extends north from the town of Hawks Nest (32°39'S; 152°11'E). In 1941, the area was undeveloped, as shown in the 1951 aerial photograph (Figure 1), with only a few houses, a general store, a road to the beach and a small caravan park. The sites referred to in this paper are shown in Figure 1 as: Site A, near Hawks Nest, where detailed transect surveys were conducted in 1941 and repeated nearby in 1997 and 1999; Sites B and C, the general location of surveys of the vegetation of the Myall Lakes area, first by Osborn and Robertson (1939), who provided a composite list of plant species found on the strand, fore-dune and fixed dune in the late 1930s, and more recently by Myerscough & Carolin (1986); Site D, the location of a survey by Kohler et al. (1995), conducted to assess the impact of herbicide spraying on native plant species.

Sand mining on Bennetts Beach, from Hawks Nest north along the coast, commenced in 1968, resumed in 1971–72, and again post-1986 (D. Stoupe, BHP Titanium Minerals Pty Ltd, Hawks Nest, pers. comm.). Mined areas appear clearly in the aerial photograph of 1984 (Figure 1) as broad bands of cleared vegetation, one of which extends along the beach, often from the high tide mark and all the foredune to the hind dune. At Bennetts Beach, the old stabilized dunes consist of alternating swales and ridges, and appear as multiple, parallel lines in the 1951 photograph in Figure 1.

Methods

Detailed vegetation sampling — 1941, 1997 and 1999

In 1941, vegetation was sampled in a 0.5 ha study site, extending for 114 m from a baseline above the beach face, across the foredune complex, windward and lee slope of the foredune ridge, to the swale. The location, now part of the golf course, is labeled 'A' on the 1951 photograph in Figure 1. Eleven parallel transect lines were established 15 ft (4.6 m) apart. Data were collected in contiguous rectangular quadrats (4.6 m × 0.9 m) along each transect line for a maximum length of 25 quadrats (114 m). Fence-lines and adjacent land ownership made the grid outline in 1941 slightly irregular (see shaded portion of Figure 2).

This procedure was repeated in 1997 and 1999, in two locations, 250 m apart (labelled 'A' on the 1984 photograph in Figure 1), just north of the caravan park and golf course at Hawks Nest. These locations were selected to be near to the 1941 study without being obviously affected by foot or vehicle traffic or other disturbances. In was impossible to use the exact location of the 1941 survey because development had destroyed the site. In each of the 1990s surveys, the parallel transects extended from the strand to the swale margin of the main dune, which was 28 contiguous 4.6 m quadrats (130 m) in 1997 and 37 quadrats (170 m) in 1999. These two study plots clearly span the strip that was mined for sand, clearly seen in the 1984 aerial photograph (Figure 1).

In 1941, the percent cover of grasses, forbs, recumbent and tufted herbs was estimated by eye and numbers of erect herbs, small and tall shrubs and trees were counted in each 4.6 m × 0.9 m quadrat. In 1997 and 1999, percent cover was estimated by eye for all species. The 1941 density data for the erect herb, shrub and tree species were converted to % cover by multiplying by 5%, as these were relatively small plants in 1941 and a pilot study in 1997 indicated that the 5% conversion was a reasonable approximation for these species. These cover estimates were used to plot the spatial distributions of all species across the fore dune – hind dune gradient. For each species, cover was averaged across each corresponding quadrat position over the 11 transects, and this measure was then expressed as a moving average of each respective quadrat position and the adjacent quadrat (Figure 2). These data were used to prepare graphs illustrating the change in % cover across the dune, for the more common plant species, in each of the three surveys.

Fine-scale distributions of three dominant shrub species (*Leptospermum laevigatum*, *Monotoca elliptica* and *Banksia integrifolia*) and two dominant herb species (*Hibbertia scandens* and *Scaevola calendulacea*) were described using isonome maps (Pidgeon & Ashby 1942; Brewer 1995). For the three shrubs, the relative density of the species was calculated, as a percentage, for each quadrat (e.g. 15 individual plants of *Leptospermum laevigatum*, out of a total of 20 plants in a quadrat, yields a relative abundance score of 75%). For the herb species, this score was based on the cover estimates for the two herb species. The percentage scores for individual species were then plotted on separate maps of the grid, and lines drawn to connect areas of equal relative density values, in the same was as contour maps are drawn (Brewer 1995). These lines, or 'isonomes' (from *iso* = equal and *noma* = distribution) are essentially contours of equal relative density.

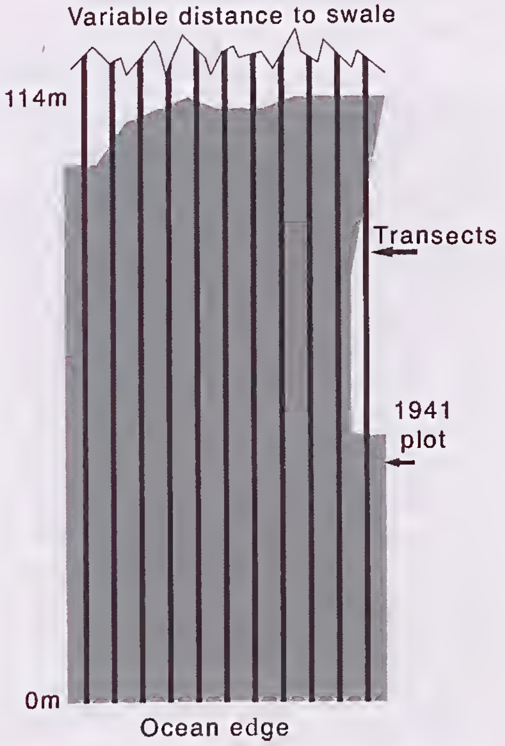

Fig. 2. Outline of the vegetation survey layout at site A (see Fig. 1) in 1941, repeated in 1997 and 1991. Vegetation data from contiguous 4.6 x 0.9 m quadrats in parallel transects, 4.6 m apart, were used to quantify zonation across the dune (see Fig. 3) and to assess phytosociological patterns using isonome mapping (see Fig. 4).

General surveys in 1939, 1986 and 1995

Osborn and Robertson (1939) described the vegetation of the Myall Lakes based on three surveys (spanning 1934 and 1935). Their species lists of the coastal vegetation appear to be composites from the three visits to the area, collected mostly in what is now Myall Lakes National Park. Three dune zones identified by Osborn and Robertson, 'strand', 'fore-dune' and 'fixed dune', support the vegetation that was examined in detail in our studies.

Myerscough and Carolin (1986) defined the plant communities occurring on sands and headlands in the coastal portion of Myall Lakes National Park, and prepared a vegetation map of the area. Their study area broadly overlaps the area surveyed by Osborn and Robertson (1939), to the north of our detailed Hawks Nest vegetation surveys. The plant communities defined by Myerscough and Carolin (1986) that represent the vegetation of our studies are 'foredune complex' and 'beach-dune thicket'. Although some of the area surveyed by Myerscough & Carolin had been mined for sand, their vegetation descriptions were based on what they refer to as the 'putative undisturbed state'. Their species lists for the two relevant communities appear to have been based on a transect just north of Bombah Broadwater, about 25 km north of our study sites.

Kohler et al. (1995) reported an experimental study designed to assess the impact on native plant and animal species of aerial herbicide spraying to control bitou bush (*Chrysanthemoides monilifera*). This site extends for 2 km, from about 3 km north of Hawks Nest virtually to the southern boundary of the Myall Lakes National Park. The sand dune vegetation was divided in to contiguous strips, 44 m wide, representing a range of herbicide treatments and untreated controls. Vegetation was surveyed in 10 of these treatment strips, using 5 m wide transects that extended approximately 100 m, from the western edge of the hind dune to the ocean edge of the foredune.

Comparisons of species in surveys

Species recorded in each of the surveys were classified as either native or introduced to Australia. The native species were further categorised as being (i) strongly associated with sand dune habitats, (ii) naturally occurring in sand dunes but also occurring commonly in a range of other habitats, and (iii) characteristic of habitats other than sand dunes. Decisions were based on information contained in Myerscough & Carolin (1986), Clarke (1989a,b), Clarke & Chapman (1989), Chapman (1989), Carolin & Clarke (1991), Benson & McDougall (1993), and Harden (1993).

Results and discussion

Vegetation composition

Twenty-five species were recorded in the 1941 survey (Table 1). Of these, 9 were considered to be closely associated with sand dunes, 15 were other native species that are also commonly found in other habitats, and one is a cosmopolitan weed species (*Cakile edentula*). The survey by Osborn and Robertson (1939) at Myall Lakes adds six species to this list of 25: *Apium prostratum, Calystegia soldanella, Correa alba, Dodonaea triquetra, Euphorbia sparmanii,* and *Senecio spathulatus*. This is perhaps understandable, because the Osborn & Robertson list is a composite of several visits, the total area searched was certainly greater than the 11 transects surveyed in 1941 (Robertson pers. comm.), and the site was 15–20 km further north.Comparing the 1941 list with the 1997 and 1999 studies, conducted in the same way in the same area (close to Hawks Nest), reveals seven species that were absent in the later two surveys (*Actites megalocarpus, Austrofestuca littoralis, Breynia oblongifolia, Conospermum taxifolium, Leucopogon parviflorus, Pomax umbellata* and *Stephania japonica*). Only one of these (*A. littoralis*) was also absent in the other recent surveys (1986 & 1995). There were, however, many new species (21) recorded at Hawks Nest in 1997/99. Nine of these additional species are introduced weeds and 10 are native species more typical of heath, woodland and forest communities (Table 2; see also Clarke 1989b), and are listed by Myerscough & Carolin (1986) as being present in communities other than 'foredune complex' or beach-dune thicket' (see Table 1).

It is striking that the 1941 study detected only one exotic weed species, *Cakile edentula*, which has a cosmopolitan distribution (Carolin & Clarke 1991). Osborn and Robertson found *Cakile edentula* and also *Oxalis corniculata*, which also has a cosmopolitan distribution (although even this may have been a native *Oxalis* taxon such as *Oxalis rubens*; D. Benson pers. comm.). The later studies all reported many weed species, including invasive species such as *Chrysanthemoides monilifera* and *Ipomoea cairica*.

Vegetation profile across the dune

The distributions and densities, over the 0.5 ha study area at Bennetts Beach, of the 29 species recorded in the sample quadrats in 1941 are shown in Figure 3 (a) in relation to the dune profile (from Brewer 1941). A set of species was clearly confined to the foredune, just above the strand, with *Spinifex sericeus* and *Carpobrotus glaucescens* dominating; although in this region there was a high percent cover of bare sand. *Hibbertia scandens* and *Scaevola calendulacea* dominated the lower slope of the foredune ridge, associated with a number of other species, including the most seaward appearance of shrub species. From the upper windward slope and dune crest to the swale, *Monotoca elliptica* and *Leptospermum laevigatum* were obvious dominants. These two shrub species had the greatest ecological amplitudes, experiencing exposure to salt-laden winds on the seaward face of the foredune ridge and also shelter and higher humidity on the lee slope and swale, where they formed closed-canopy thickets with sparse ground flora and some species of climbers. The transects finished at 114 m; beyond this there was a sharp ecotone (at *c.* 120 m) to open woodland of *Banksia serrata*. This species covered the undulating barrier ridges to about 160 m. A low heath separated the *B. serrata* woodland from *Eucalyptus pilularis* open forest, which extended to 230 m.

Table 1. Plant species recorded from four sites in the lower north coast, NSW.

Site A (Bennetts Beach): Pidgeon (1941) and this study (1997 & 1999); Site **B**: Osborn & Robertson (1939); Site **C**: Myerscough & Carolin (1986); Site **D**: Kohler et al. (1995) [see Fig. 1 for location of sites].

# represents species recorded by Myerscough & Carolin from plant communities other than 'beach-dune thicket' or 'foredune complex'.

d: denotes species that are strongly associated with coastal dunes, although some occur in other nearby habitats such as coastal headlands and heaths.

N: denotes native species that occur naturally on dunes but are not restricted to that habitat.

O: denotes species that are native to other Australian plant communities but do not naturally occur in these coastal dunes.

W: denotes weed species introduced to Australia.

Status	**Species**	**A**			**B**	**C**	**D**
		1941	1997	1999	1939	1986	1995
N	*Acacia longifolia*					+	
N	*Acacia suaveolens*			+		#	+
d	*Acacia sophorae*	+	+	+	+	+	+
N	*Acacia ulicifolia*					#	+
N	*Actinotus helianthi*					#	+
d	*Actites megalocarpus*	+			+	+	
N	*Aotus ericoides*		+			#	+
N	*Apium prostratum*				+		
W	*Arctotheca populifolium*			+			
N	*Astroloma pinifolium*		+	+		#	+
d	*Austrofestuca littoralis*	+			+		
N	*Banksia integrifolia*	+	+	+	+	+	+
N	*Banksia serrata*	+	+	+	+	+	+
N	*Billardiera scandens*					+	+
N	*Bossiaea ensata*	+	+				+
N	*Bossiaea heterophylla*						+
N	*Breynia oblongifolia*	+			+	+	+
W	*Briza maxima*						+
W	*Cakile edentula*	+	+	+	+	+	
N	*Callistemon citrinus*					#	+
N	*Calystegia soldanella*				+		
d	*Carex pumila*			+			
d	*Carpobrotus glaucescens*	+	+	+	+	+	+
N	*Cassytha pubescens*		+				+
W	*Chloris gayana*					+	
W	*Chrysanthemoides monilifera*		+	+		?	+
N	*Comesperma ericinum*						+
O	*Commelina cyanea*		+		+	+	
N	*Conospermum taxifolium*	+					+
W	*Conyza albida*		+	+			
W	*Conyza bilboana*		+	+		+	
d	*Correa alba*				+	+	+

Status	Species	A 1941	A 1997	A 1999	B 1939	C 1986	D 1995
N	*Correa reflexa*					+	
N	*Cymbopogon refractus*					+	
N	*Cynodon dactylon*		+	+		#	
N	*Dianella caerulea*	+	+	+	+	#	+
N	*Dichelachne crinata*					+	
N	*Dillwynia glaberrima*		+			#	+
N	*Dodonaea triquetra*				+	+	
d	*Euphorbia sparrmanii*				+	+	
W	*Gladiolus gueinzii*		+			+	+
N	*Gonocarpus micranthus*					+	
N	*Gonocarpus teucrioides*					+	+
N	*Hardenbergia violacea*	+		+		#	+
N	*Hibbertia fasciculata*					#	+
N	*Hibbertia linearis*		+			#	+
N	*Hibbertia obtusifolia*		+			#	+
N	*Hibbertia scandens*	+	+	+	+	+	+
d	*Hydrocotyle laxiflora*					+	
W	*Hydrocotyle bonariensis*		+	+		+	+
W	*Hypochoeris radicata*					+	
N	*Imperata cylindrica*			+		+	+
W	*Ipomea cairica*					+	
d	*Isolepis nodosa*	+	+	+	+	+	+
N	*Juncus usitatus*					+	
N	*Kennedia rubicunda*	+	+	+	+	+	+
N	*Lasiopetalum ferrugineum*					+	
d	*Leptospermum laevigatum*	+	+	+	+	+	+
N	*Leptospermum liversidgei*					#	+
N	*Leucopogon ericoides*					#	+
N	*Leucopogon lanceolatus* var. *gracilis*		+	+	+	#	+
d	*Leucopogon parviflorus*	+				#	+
N	*Leucopogon virgatus*					#	+
N	*Lomandra longifolia*	+	+	+	+	+	+
N	*Monotoca elliptica*	+	+	+	+	#	+
N	*Monotoca scoparia*					#	+
N	*Myoporum insulare*						+
N	*Opercularia varia*					+	
O	*Oxalis corniculata*				+	+	
d	*Oxalis rubens*			+			
N	*Pandorea pandorana*	+	+		+	+	+
N	*Pelargonium australe*		+		+	+	
W	*Pelargonium capitatum*		+				
N	*Persoonia lanceolata*		+	+		#	+
N	*Phebalium squameum*						+
N	*Pimelea linifolia*					+	
N	*Platysace lanceolata*		+			#	+
N	*Plectranthus parviflorus*					+	
N	*Pomax umbellata*				+	+	
O	*Portulaca oleracea*			+		+	
N	*Pteridium esculentum*	+	+	+		+	+
d	*Rhagodia candolleana*					+	
N	*Ricinocarpus pinifolius*						+
N	*Sarcopetalum harveyanum*					+	
d	*Scaevola calendulacea*	+		+	+	+	+
N	*Schoenus ericetorum*						+
N	*Senecio lautus* ssp. *maritimus*	+	+	+	+	+	+
d	*Senecio spathulatus*				+		
N	*Smilax glyciphylla*		+	+		#	
N	*Solanum cinereum*					+	
d	*Spinifex sericeus*	+	+	+	+	+	+
N	*Stackhousia spathulata*				+	+	+
N	*Stephania japonica* var. *discolor*		+				+
N	*Styphelia viridus* ssp. *viridus*						+
N	*Viola hederacea*					+	
W	*Vulpia bromoides*					+	
N	*Tetratheca thymifolia*					+	
N	*Wahlenbergia gracilis*					+	
d	*Wikstroemia indica*					+	
N	*Zoysia macrantha*					+	
Total no. species		25	36	32	31	57	55

Table 2. Comparison of total numbers and categories of species recorded in 1941 compared with 1997 and '99 at Hawks Nest.

Natives not associated with dunes	**Natives associated strongly with dunes**
Present in 1941, absent in 1997/1999	
Breynia oblongifolia[a]	*Actites megalocarpus*[a]
Conospermum taxifolium[a]	*Austrofestuca littoralis*
Pomax umbellata[a]	*Leucopogon parviflorus*[a]
Stephania japonica[a]	
Absent in 1941, present in 1997 &/or 1999	
Acacia suaveolens[ab]	*Carex pumila*
Aotus ericoides[ab]	*Oxalis rubens*
Astroloma pinifolium[ab]	
Cassytha pubescens[a]	
Commelina cyanea[a]	
Cynodon dactylon[b]	
Dillwynia glaberrima[ab]	
Hibbertia linearis[ab]	
Hibbertia obtusifolia[ab]	
Imperata cylindrica[ab]	
Leucopogon lanceolatus[ab]	
Persoonia lanceolata[ab]	
Platysace lanceolata[ab]	
Portulaca oleracea[a]	
Smilax glyciphylla[b]	

Introduced weeds

Present in 1941, absent in 1997/1999	Absent in 1941, present in in 1997 and/or 1999
—	*Arctotheca populifolia*
	Chrysanthemoides monilifera
	Conyza albida
	Conyza bilboana
	Gladiolus gueinzii[a]
	Hydrocotyle bonariensis[a]
	Pelargonium capitatum

Total	**Introduced weeds**	**Natives not assoc. with dunes**	**Natives associated strongly with dunes**
1941 (25)	1	15	9
1997 (36)	5	26	5
1999 (32)	5	19	8

[a] also present in the dunes in one of the later surveys at Myall Lakes (1986 and/or 1995)

[b] recorded in Myerscough and Carolin in another community, not in Foredune Complex or Beach-dune Thicket.

Broadly similar patterns of distribution and density across the dunes were evident in the 1997 and 1999 studies at Hawks Nest: *Spinifex hirsutus* was obviously a foredune species; *Carpobrotus glaucescens* mostly occurred on the windward part of the foredune; *Monotoca elliptica* favoured the dune crest to the swale; and *Leptospermum laevigatum* clearly dominated the leeward part of the foredune and the swale. These patterns were detectable even though the post-mining topography differed somewhat. The eastern face of the dune was shallower and the dune crest flatter and broader (Figure 3 (b)). Thus, the 50 m point in the 1941 study represents the location of the hind-dune slope whereas this topographic feature occurs at 160 m in the 1999 study.

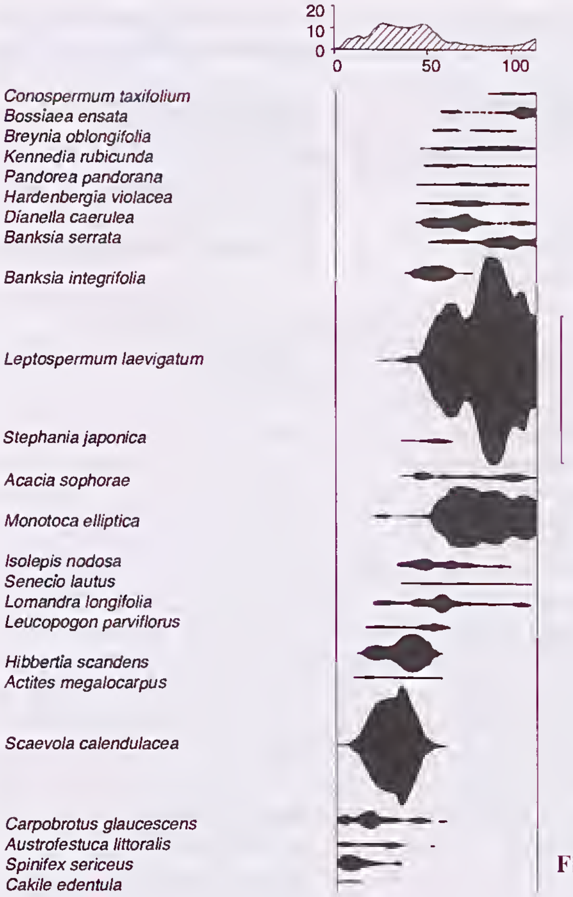

Fig. 3a.

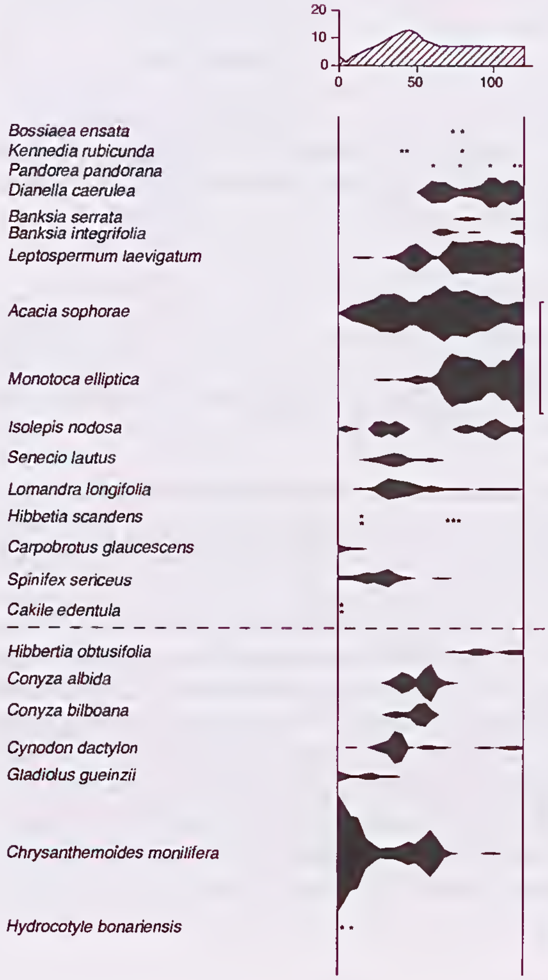

Fig. 3b.

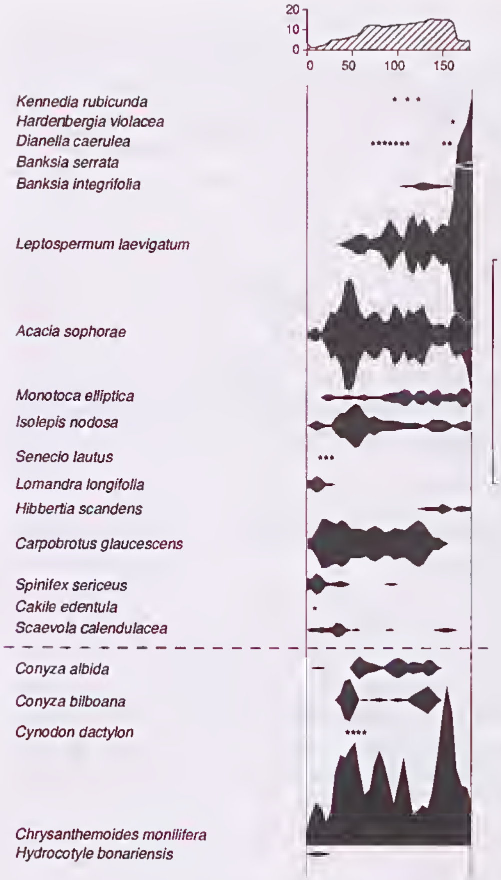

Fig. 3c.

Fig. 3 (a,b,c). Diagrams of variation in abundances of the more common plant species across the sand dunes at Site A (a) from Pidgeon (1942), and from this study (b) in 1997 and (c) in 1999. Each polygon represents a separate species and the width of the bar represents the mean of the % cover values for that species over the 11 transects, at the particular distance from the seaward edge of the plot. The scale bar on the right of each figure represents 50% cover. The polygons below the dashed lines in (b) and (c) are the species that were not present in the initial survey in 1941. Spots (small asterisks) represent rare occurrence of species at a % cover too low to be represented by polygons.

Even taking into account the topographic differences, there are some contrasts in distributions of particular species between the studies. First, *Chrysanthemoides monilifera* occurred only in the 1997 and 1999 transects, where it was most abundant on the foredune slope and crest. Perhaps the presence of *C. monilifera* accounts for the rarity of *Scaevola calendulacea* in 1997 and 1999 compared to 1941. The abundance of *Acacia sophorae* was much greater in the later two studies than in 1941. Several species extended further seaward in the later surveys than in 1941, including *Leptospermum*, *Acacia*, and *Isolepis nodosa*.

While it is tempting to interpret differences between the 1941 and the later surveys as representing change over time, it is important to recognise that there are differences between the two nearby sites that were studied in 1997 and 1999, indicating that spatial differences may be substantial. The topography of these two later sites also differed quite markedly.

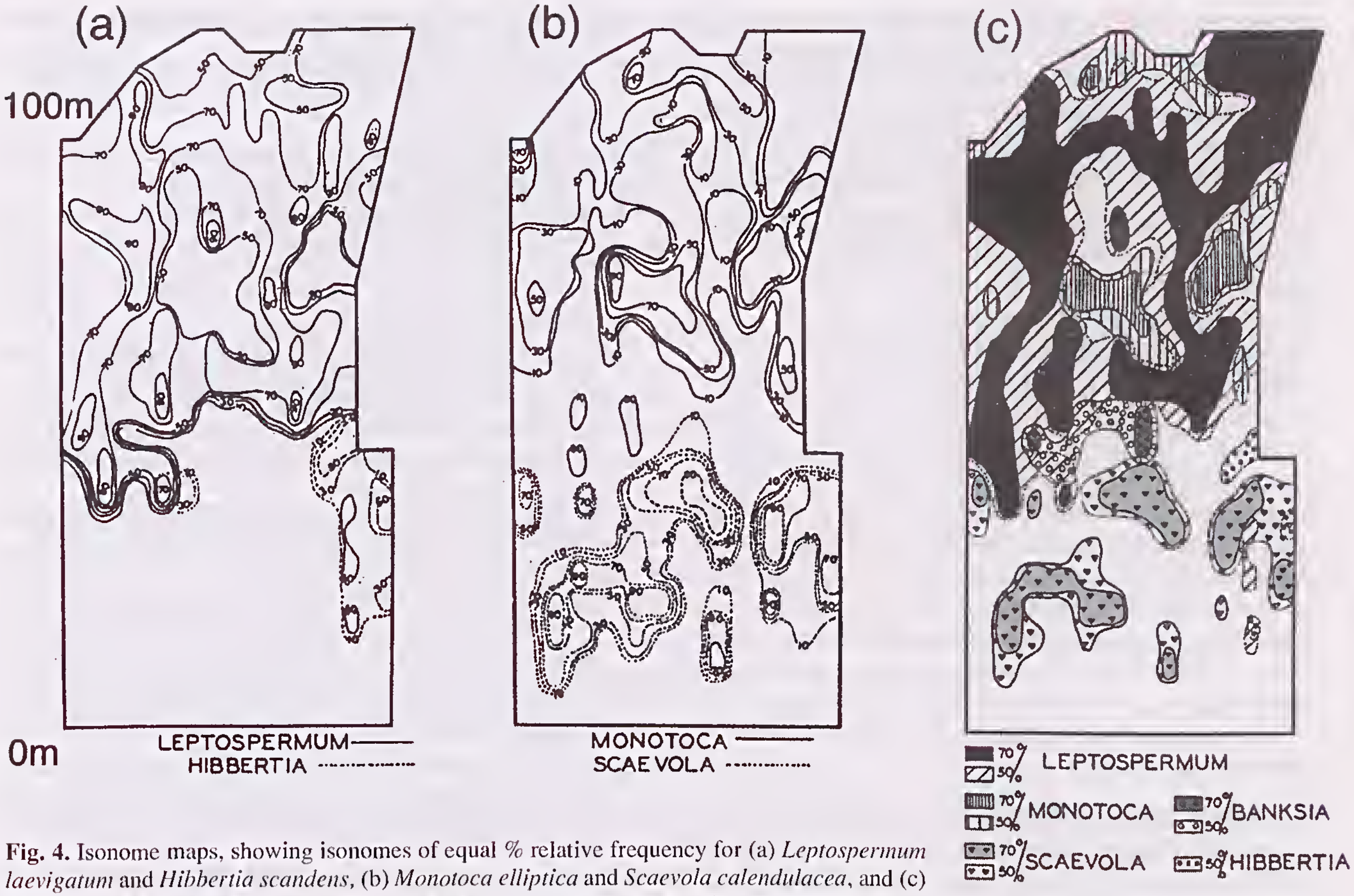

Fig. 4. Isonome maps, showing isonomes of equal % relative frequency for (a) *Leptospermum laevigatum* and *Hibbertia scandens,* (b) *Monotoca elliptica* and *Scaevola calendulacea,* and (c) all four species plotted together, along with *Banksia integrifolia,* for the 50% and 70% isonomes (reproduced from Pidgeon 1942).

Phytosociology

Isonome maps (showing isonomes from 10% to 90% relative density, with 20% intervals) for *Leptospermum laevigatum* and *Hibbertia scandens* are shown in Figure 4 (a) and for *Monotoca elliptica* and *Scaevola calendulacea* in Figure 4 (b). The two dominant shrubs, *Leptospermum laevigatum* and *Monotoca elliptica* had complex isonomes, with obvious centres of high relative density, covering most of the grid from about 45 m. In contrast, the dominant herbs (*Hibbertia scandens* and *Scaevola calendulacea*) were more sparsely distributed. Centres of high relative density of these four species are shown together, along with *Banksia integrifolia,* in Figure 4 (c). Five isonome maps have been superimposed, using only two categories of relative density (50–70% and > 70%). This composite pattern of distribution reveals a clear pattern in which there are obvious centres of high relative density surrounded by lower relative densities. One interesting feature of the composite map is the integrity of the centres of high relative density (> 70%) of *Monotoca elliptica* and *Leptospermum laevigatum.* These patterns are not evident by visual inspection of the vegetation at the site.

Attempts to construct isonome maps from the data collected in the 1997 and 1999 studies failed because there were no centres of high relative density. Rather, each of the more abundant species appeared to be distributed randomly within its zone.

Conclusions

This comparison of sand dune vegetation in the 1930s and 1940s with similar sites in the 1990s has revealed marked differences. There are many more cosmopolitan weed species present now than 60 years ago. The authentic dune vegetation at Hawks Nest displayed a clear zonation pattern, with particular species favouring different regions of the dune profile. Furthermore, dominant species showed a clear phytosociological pattern in 1941, revealed in isonome maps. Now, after sand mining and spread of invasive weeds, the zonation is not as clear, with several species extending more broadly across the dune, and no phytosociological patterns detectable for any of the dominant species.

We propose that a combination of processes has altered the vegetation of the Hawks Nest site. First, sand mining eliminated the original vegetation and reformed the dune topography. Second, revegetation after sand mining resulted in many species being planted across the dunes, with seeds sourced from a range of plant communities (thus explaining the presence of species such as *Acacia suaveolens,* see Table 1; Morrison & Rupp 1995). Buckney & Morrison (1992) also found that the restored plant community in sand-mined forest at Myall Lakes differed markedly from adjacent, unmined forest, and that the communities in the mined area were actually diverging from the original, unmined community over a 15 year period. It is interesting that in these forest sites, two species usually associated with the coastal dunes, *Carpobrotus glaucenscens* and *Leptospermum laevigatum,* occurred in mined areas but not in four, adjacent, unmined areas. This supports the conclusion that a wide range of native species were used in post-mining habitat restoration.

In the coastal sand dune community we studied, it seems that insufficient time has passed for the species that were established after mining to reassort themselves into a community resembling the authentic composition and structure detected in the early studies. Indeed, the physical reforming of the dunes and appearance of invasive and highly competitive weeds such as *Chrysanthemoides* may prevent the process of species reassortment. We suggest that future revegetation programs in sand dunes should take account of the zonation patterns present in the original sand-dune vegetation, planting only appropriate species (that are associated with dune communities) and confining them to the correct zones. For some species (e.g. *Leptospermum* and *Monotoca*), the isonome data suggest that planting in dense clusters would better approximate their distributions in the authentic dune communities.

Acknowledgements

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Vegetation of Ironbark Nature Reserve and *Bornhardtia* Voluntary Conservation Agreement, Northern Tablelands, New South Wales

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Abstract: The vegetation of Ironbark Nature Reserve (1603 ha) and *Bornhardtia* Voluntary Conservation Agreement (704 ha), 75 km north west of Armidale, 30 km north east of Barraba (30°19'S, 150°53'E) in the Barraba Shire, in the Northern Tablelands Bioregion NSW, is described. Eleven communities are defined based on flexible UPGMA analysis of cover-abundance scores of all vascular plant taxa. These communities are mapped based on ground truthing, air photo interpretation and substrate. All communities are simple in structure being primarily of woodlands or shrublands.

Communities described are: (1) *Eucalyptus macrorhyncha* (Red Stringybark) – *Eucalyptus blakelyi* (Red Gum) Woodlands, (2) *Eucalyptus caleyi* (Caley's Ironbark) – *Eucalyptus andrewsii* (Western New England Blackbutt) Woodlands, (3) *Eucalyptus prava* (Orange Gum) – *Eucalyptus andrewsii* (Western New England Blackbutt) Woodlands, (4) *Eucalyptus dealbata* (Tumbledown Gum) – *Eucalyptus caleyi* (Caley's Ironbark) Woodlands, (5) *Eucalyptus prava* (Orange Gum) – *Eucalyptus blakelyi* (Red Gum) Woodlands, (6) *Eucalyptus quinniorum* (Quinn's Gum) – *Eucalyptus prava* (Orange Gum) Forests, (7) *Angophora floribunda* (Rough-barked Apple) – *Eucalyptus blakelyi* (Red Gum) Woodlands, (8) *Casuarina cunninghamiana* (River Oak) – *Eucalyptus blakelyi* (Red Gum) – *Angophora floribunda* (Apple) Forests, (9) *Calytrix tetragona* (Fringe Myrtle) – *Ozothamnus obcordatus* (Daisy Bush) Open Shrublands, (10) *Homoranthus bornhardtiensis* Open Shrublands and (11) *Leptospermum polygalifolium* (Tea-tree) Wetland.

All communities described here are inadequately represented in the conservation network with one (White-Box – Yellow-Box – Blakely's Red Gum Woodland) listed as endangered on the NSW *TSC Act*. Both conservation areas and neighbouring parcels of land contain extensive areas of little disturbed high quality 'old growth'. 38 species are of conservation significance of which one is listed as Vulnerable and one Endangered on the NSW *TSC Act*. The broader remnant is under increasing pressure for clearing for grazing production and the combined area of both reserves is considered to be inadequate to protect the significant features of the local region.

***Cunninghamia* (2003) 8(1): 93–110**

Introduction

Ironbark Nature Reserve and the adjoining land of the *Bornhardtia* Voluntary Conservation Agreement (VCA) are located within Northern Tablelands Botanical Division, 75 km north west of Armidale and 30 km east north east of Barraba (lat 30°19'S long 150°53') (Figure 1). They lie in the New England Tablelands Bioregion though the western boundary of Ironbark NR and the southern boundary of the VCA correspond with the Nandewar and Northern Tablelands Bioregion's common boundary. Both areas are within the local government area of Barraba Shire and the County and Parish of Darling. At present, Ironbark Nature Reserve covers 1603 ha and *Bornhardtia* VCA , an additional 750 ha (including 36 ha of road reserves). *Bornhardtia* adjoins nearly 2 km of the south eastern boundary of the Nature Reserve and runs south for almost five kilometres. The Ironbark 9037-II-N 1: 25 000 map sheet covers the majority of the area with a small portion on the Linton 9037-II-S 1: 25 000 sheet. All current boundaries are with freehold lands.

This paper gives part of the results of a flora survey to provide baseline data for the joint management plan for the Nature Reserve and the Voluntary Conservation Agreement (VCA) to map vegetation communities and to provide information on the distribution of rare or geographically restricted or disjunct taxa. This information will be used to assist the development of appropriate management strategies (Hunter 2002a). A VCA is an agreement negotiated between the Minister for the Environment and private landholders. The agreement is binding and is registered on the title of the land. The name of the private property is *Bornhardtia*, hence the agreement is the *Bornhardtia* VCA.

Climate and landform

The median rainfall for the area is 773 mm per annum but fluctuates greatly, with yearly rainfall from as little as 473 mm up to 1108 mm per annum. On average seasonal rainfall peaks between October and January, with January being the highest rainfall month. Seasonal snowfalls occur but are rare, though frosts are common in the winter months. Average annual temperature varies from 14.6–17.7°C, with an average maximum of 32°C and minimum of –2.2°C. Climate varies greatly over the study area due to the rugged topography and changes in elevation.

The study area is a rugged landscape located on an eastern arm of the Nandewar Range. Elevation ranges from 640 m at the

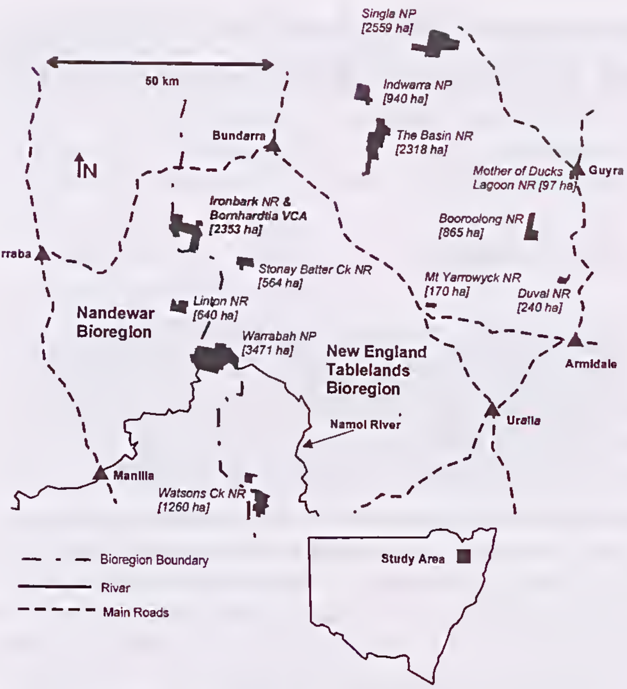


Fig. 1. Location of Ironbark Nature Reserve and *Bornhardtia* Voluntary Conservation Agreement, and nearby conservation areas in northeastern NSW.

point where Long Swamp Creek leaves the Nature Reserve to 1010 m at the top of Little Bald Rock within *Bornhardtia*.

The topography is dominated by exposed inselbergs, flatrocks, boulder piles, boulder fields and subsurface flatrocks. Areas of low relief are uncommon but in some small areas sections occur along deeply incised sections of Long Swamp Creek.

Drainage flows to the west. The majority of water from *Bornhardtia* flows into Bald Rock Swamp Creek which later joins to Long Swamp Creek on the southern boundary of Ironbark NR. All water catchments within both conservation areas drain into Long Swamp Creek, which joins Ironbark Creek to the west. Ironbark Creek then heads south to join the Namoi River; this flows into Lake Keepit.

Geology

Ironbark and *Bornhardtia* are situated within the Central Block (Gilligan & Brownlow 1987) of the southern New England Orogen, east of the Tamworth Belt and the Peel Fault System. The majority of the study area is within the Bundarra Plutonic Suite, an S-type post-tectonic unstressed granitoid belt of about 290 million years old that runs from Howell (Copeton Dam) south of Inverell, south to Bendemeer north of Tamworth (Ashley & Flood 1997). The western boundary of Ironbark at the point that Long Swamp Creek leaves the reserve is a small area of the Whitlow Formation that includes low-grade regionally metamorphosed and multiply deformed lithic wacke. Minor inclusions of the Cara Formation, that includes low grade regionally metamorphosed and multiply deformed metabasalt, also occur here and in a few minor localities within Ironbark.

European landuse and history

Portion 3 of the Shire of Barraba, Parish and County of Darling, resumed from sale on the 4 August 1897, forms the majority of Ironbark Nature Reserve. By 1897, the more open areas with deeper soil along Long Swamp Creek had been cleared with some areas showing regrowth (Plan of Portion 3, Parish Map LB 98/3137, 1898). Prickly Pear was noted to be infesting at least a quarter of the portion. By 1911 areas included within the current Reserve had been ring-barked with suckers mattocked or thick regeneration occurring (Plan of Portion 3, Parish Map SL082, 1911) Up until the area was taken over by the National Parks & Wildlife Service in 1985 it was grazed and Long Swamp Creek burnt for green pick up for stock. Areas in the south-eastern corner of Ironbark also appear to have been selectively cleared in the past.

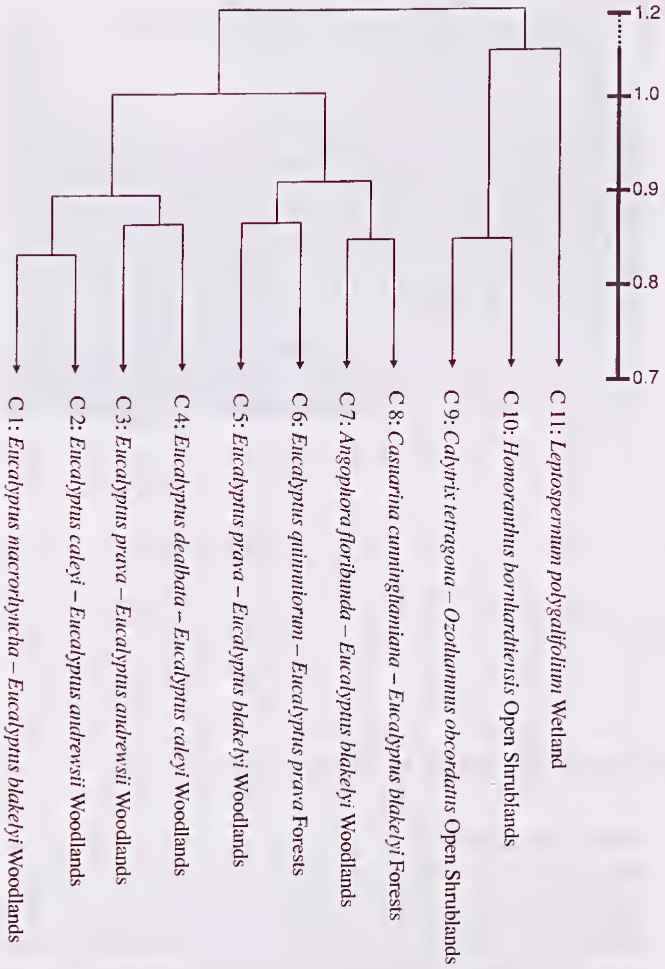
Much of *Bornhardtia* appears to have been unmodified, particularly the southern two thirds. It originally formed part of the Ironbark and Tea-tree Gold Fields and then *Stoney Batter* which was gazetted as a pastoral holding in 1851 and included 204 800 acres, of which 66 560 was considered to be mountains and scrub (Harris 2000). Areas in the northern third of the property appear to have been partially cleared, particularly in the north-eastern corner which adjoins and had similar past treatment to adjoining areas in Ironbark. Creeklines, particularly the larger ones had been burnt seasonally for green pick. The top third of the property was used for winter grazing between the later 1980s and 1997 when this practice stopped after purchase by the current owners. A small area of approximately 20 ha was selectively cleared and ring-barked in the mid-1990s by the previous owner.

Ironbark Nature Reserve was gazetted in November 1985 with 1230 ha; an additional 373 ha adjoining the eastern boundary purchased in 1988 to incorporate a significant cultural heritage site. *Bornhardtia* was subdivided and purchased from *Granite Heights* in 1997. On the 18 October 2001, under a Voluntary Conservation Agreement, 704 ha (excluding road reserves and 9.5 ha in the southeastern corner) were gazetted. The derivation of the property name is from a 'Bornhardt', a basic inselberg feature described as a large dome-shaped monolith, bald and steeply sided with few fractures whereas the surrounding landscape is highly fractured (Twidale 1982).

Within close proximity and conserving similar vegetation types are Stoney Batter Nature Reserve (563 ha, gazetted in 1999); Linton Nature Reserve (161 ha, gazetted in 1979; and Warrabah National Park (3556 ha, gazetted in 1984), the largest reserve in the region. Despite the number of reserves in the general vicinity, all combined there are only 6587 ha of land conserved in the region.

Previous investigations

Greg Roberts, local NPWS ranger and naturalist visited Ironbark Nature Reserve on its dedication and provided a brief synopsis of the major floristic patterns and some of the more unusual species (Roberts, unpublished). Roberts completed


1.2
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C 1: *Eucalyptus macrorhyncha – Eucalyptus blakelyi* Woodlands
C 2: *Eucalyptus caleyi – Eucalyptus andrewsii* Woodlands
C 3: *Eucalyptus prava – Eucalyptus andrewsii* Woodlands
C 4: *Eucalyptus dealbata – Eucalyptus caleyi* Woodlands
C 5: *Eucalyptus prava – Eucalyptus blakelyi* Woodlands
C 6: *Eucalyptus quinniorum – Eucalyptus prava* Forests
C 7: *Angophora floribunda – Eucalyptus blakelyi* Woodlands
C 8: *Casuarina cunninghamiana – Eucalyptus blakelyi* Forests
C 9: *Calytrix tetragona – Ozothamnus obcordatus* Open Shrublands
C 10: *Homoranthus bornhardtiensis* Open Shrublands
C 11: *Leptospermum polygalifolium* Wetland

Fig. 2. Summary dendrogram of the full floristic dataset of sites using Kulczynski association and flexible UPGMA fusion strategy.

a masters preliminary thesis on the vegetation on granite on the Northern Tablelands and North Western Slopes, but no sites were placed in the study area (Roberts 1983). Roberts (1992) mapped the vegetation of the region using LANDSAT TM images. As part of the owner's application for NPWS purchase of *Granite Heights*, the author made a checklist of 120 species on a half-day visit in 1996 during a preliminary investigation of the property (Hunter, unpublished). Hunter returned later in 1996 and placed 30 × 0.1 ha full floristic survey sites (Hunter & Clarke 1998; Hunter 1999). Hunter described two new species from what was to become *Bornhardtia* (Hunter 1998; Hunter & Bruhl 1999).

Methods

Vascular plants were scored using the Braun-Blanquet (1982) six point cover abundance scale from 110, 20 × 20 m quadrats. Quadrats were placed using a stratified random method using altitude, aspect and physiography (crest & upper slope, lower slope & flats, open depressions). The survey was conducted over a period of 14 days during September 2001 and April 2002.

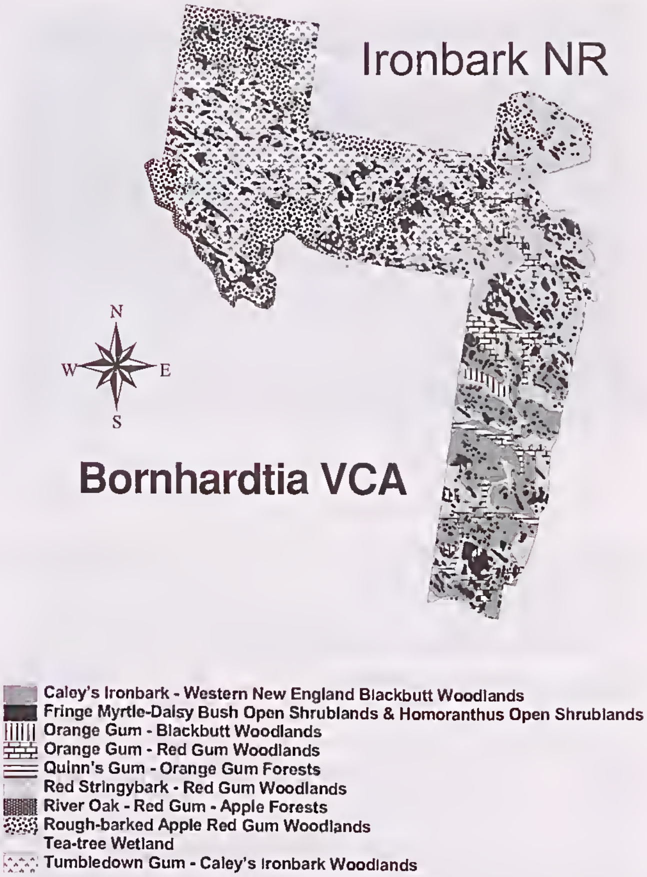
Ironbark NR
N
W
E
S
Bornhardtia VCA
Caley's Ironbark - Western New England Blackbutt Woodlands
Fringe Myrtle-Daisy Bush Open Shrublands & Homoranthus Open Shrublands
Orange Gum - Blackbutt Woodlands
Orange Gum - Red Gum Woodlands
Quinn's Gum - Orange Gum Forests
Red Stringybark - Red Gum Woodlands
River Oak - Red Gum - Apple Forests
Rough-barked Apple Red Gum Woodlands
Tea-tree Wetland
Tumbledown Gum - Caley's Ironbark Woodlands

Fig. 3. Map of vegetation communities for Ironbark Nature Reserve and *Bornhardtia* Voluntary Conservation Agreement.

Good quality specimens were retained as vouchers by the New England Tablelands Region of the NSW NPWS and duplicates of significant collections submitted to the National Herbarium of NSW. Nomenclature follows that of Harden (1990–1993) except where recent changes have been made.

Analyses and data exploration were performed using options available in the PATN Analysis Package (Belbin 1995a, b). For final presentation of results all species and their relative abundance scores were used and the analysis performed using Kulczynski association measure which is recommended for ecological applications (Belbin 1995a, b) along with flexible Unweighted Pair Group arithMetic Averaging (UPGMA) and the default PATN settings.

Delineation of community boundaries in Figure 3 was based on the location of sites and their position within the multivariate analysis, air photograph interpretation, substrate and ground truthing. The vegetation map is based on a 1:25 000 scale. Structural names follow Specht et al. (1995) and are based on the most consistent uppermost stratum.

Results

Eleven communities were recognised at the dissimilarity measure of c. 0.8. A summary of the community relationships is given in the dendrogram (figures 2 & 3). A

Community	Number of sites	Richness per 400 m² (average)	Number of Species	Number of Introduced Species	Proportion of reserves	Number of Hectares
C 1: *Eucalyptus macrorhyncha* – *Eucalyptus blakelyi* Woodlands	20	35–54 (44.8)	179	11	20.3%	548.9
C 2: *Eucalyptus macrorhyncha* – *Eucalyptus andrewsii* Woodlands	21	29–52 (41.6)	168	7	9.5%	255.2
C 3: *Eucalyptus prava* – *Eucalyptus andrewsii* Woodlands	6	16–45 (28.7)	92	0	1.2%	32.0
C 4: *Eucalyptus dealbata* – *Eucalyptus caleyi* Woodlands	8	24–46 (36.3)	110	3	28.8%	778.5
C 5: *Eucalyptus prava* – *Eucalyptus blakelyi* Woodlands	8	33-65 (49.5)	179	21	3.7%	100.8
C 6: *Eucalyptus quinniorum* –*Eucalyptus prava* Forests	10	32-67 (49.6)	164	7	1.6%	43.6
C 7: *Angophora floribunda* – *Eucalyptus blakelyi* Woodlands	15	22-60 (37.1)	165	17	18.1%	490.1
C 8: *Casuarina cunninghamiana* – *Eucalyptus blakelyi* Forests	3	30-39 (33.7)	73	11	1.4%	38.2
C 9: *Calytrix tetragona* – *Ozothamnus obcordatus* Open Shrublands	9	19-24 (20.2)	79	2	?7.6%	?206.0
C 10: *Homoranthus* Open Shrublands	9	17-38 (25.6)	107	3	?7.6%	?206.0
C 11: *Leptospermum polygalifolium* Wetland	1	21	21	3	0.1%	3.4

Table 1. Selected attributes of the eleven defined communities at Ironbark Nature Reserve and the *Bornhardtia* VCA.

total of 477 vascular plant taxa were recorded from 140 sites overall. From the 110 survey sites for this work 402 taxa were recorded. A further 75 taxa were recorded opportunistically and collated from previous surveys. The number of taxa captured represents about 7% of the total NSW flora and about 24% of the flora of the Northern Tablelands.

The 477 taxa occurred in 93 families and 269 genera. The families with the greatest number of taxa are: Asteraceae (55), Poaceae (53), Fabaceae (49), Myrtaceae (24), Cyperaceae (22), Orchidaceae (20), Juncaceae (11), Caryophyllaceae (11), Rubiaceae (10), Apiaceae (10), Epacridaceae (9) and Proteaceae (9). The richest genera are: *Acacia* (14), *Eucalyptus* (11), *Juncus* (10), *Cyperus* (8), *Hibbertia* (6), *Leptospermum* (6), *Pterostylis* (6), *Brachyscome* (5), *Goodenia* (5), *Leucopogon* (5), *Lomandra* (5), *Olearia* (5), *Pultenaea* (5), *Senecio* (5), *Wahlenbergia* (5).

Vegetation communities

Many of the vegetation communities within Ironbark Nature Reserve and *Bornhardtia* Voluntary Conservation Agreement are woodlands with either a predominantly shrubby or grassy understorey. Shrublands and herbfields do occur but are of restricted distribution primarily on shallow skeletal soils. Grasslands, except for those of a derived nature, were not found. Sedgelands were also missing, apart from minor occurrences directly associated with creek banks. Forests are found, but these are infrequent and usually associated with protected sites on deeper soils. *Callitris endlicheri* is the most prominent tree species in the area and has often been subsumed in the community names to enable greater differentiation of floristic units. Other overstorey trees are ubiquitous or at least subdominant in several assemblages. The general fidelity of associated understorey species changes considerably allowing the recognition of communities despite many overstorey similarities. Overall, communities within the study area are *Callitris endlicheri*, *Eucalyptus blakelyi* and *Eucalyptus caleyi* subsp. *caleyi* dominant with occurrences of *Eucalyptus macrorhyncha* and *Eucalyptus melliodora* on better and deeper soils. A summary of relevant statistics for each community are presented in Table 1. Extreme values are given in brackets within the following descriptions of communities.

Community 1: *Eucalyptus macrorhyncha* (Red Stringybark) – *Eucalyptus blakelyi* (Red Gum) Woodlands

Environmental relationships: usually on mid to upper slopes but sometimes also on lower slopes and flats. Soils are usually sandy loam, loam or rarely loamy sand, are deep or shallow and are usually dark to light brown or grey brown.

Structure: primarily grassy woodlands but also shrubby woodlands and open forests. Tree layer: (12–) 20–25 (–30) m tall; 20–30 (–40)% cover. Tall shrub layer: absent. Low shrub layer: 1–3 (–4) m tall; (5–) 20–30 (–40)% cover. Understorey layer: < 1 m tall; (30–) 50–90% cover. (Fig. 4).

Trees: *Eucalyptus macrorhyncha, Callitris endlicheri, Angophora floribunda, Eucalyptus blakelyi, Eucalyptus bridgesiana, Eucalyptus melliodora, Eucalyptus prava, Eucalyptus andrewsii, Eucalyptus caleyi.*

Shrubs: *Cassinia quinquefaria, Leucopogon muticus, Hibbertia obtusifolia, Melichrus urceolatus, Pultenaea* sp. *G, Brachyloma daphnoides* ssp. *glabrum, Lissanthe strigosa, Olearia elliptica, Olearia viscidula, Hibbertia riparia, Dodonaea viscosa* var. *angustifolia, Acacia neriifolia, Acacia leiocalyx, Pultenaea* sp. *C, Indigofera adesmiifolia.*

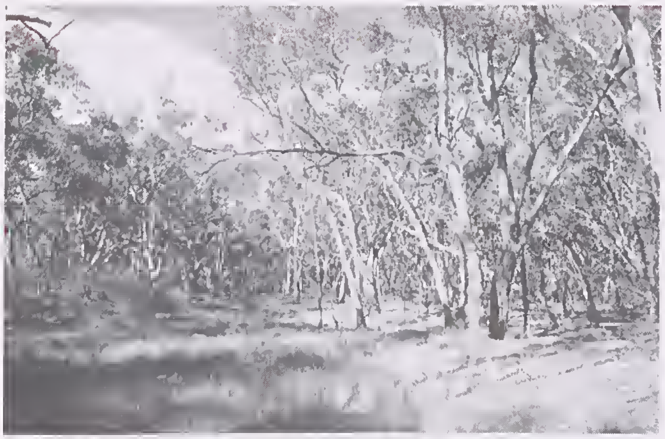

Fig. 4. Community 1 *Eucalyptus macrorhyncha* and *Eucalyptus blakelyi* Woodlands

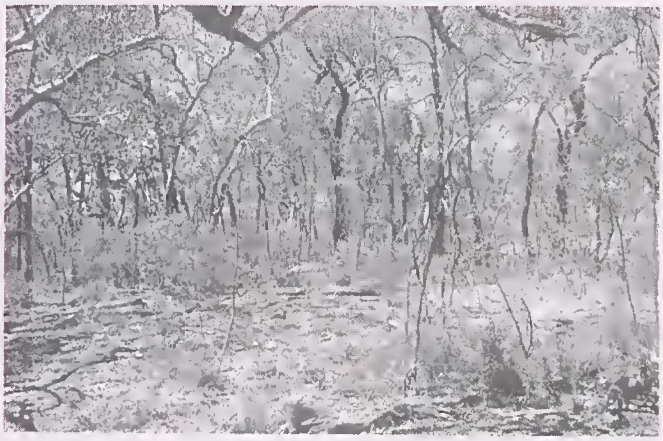

Fig. 5. Community 2 *Eucalyptus caleyi* subsp. *caleyi* and *Eucalyptus andrewsii* Woodland

Climbers & trailers: *Desmodium varians, Glycine clandestina, Hardenbergia violacea, Clematis glycinoides.*

Ground cover: *Cymbopogon refractus, Aristida vagans, Geranium solanderi* var. *solanderi, Dichelachne micrantha, Lomandra multiflora, Echinopogon caespitosus* var. *caespitosus, Luzula flaccida, Dichondra repens, Dianella caerulea, Senecio diaschides, Caladenia fuscata, Aristida calycina, Themeda australis, Cheilanthes sieberi, Hydrocotyle peduncularis, Dianella revoluta, Wahlenbergia planifolia* ssp. *pilosa, Oxalis chnoodes, Joycea pallida, Acaena novae-zelandiae, Viola betonicifolia, Veronica calycina, Goodenia macbarroni, Plantago varia, Lepidosperma laterale, Imperata cylindrica, Ranunculus lappaceus, Chrysocephalum apiculatum, Austrodanthonia laevis, Vittadinia cuneata, Scleranthus biflorus, Poa sieberiana, Microlaena stipoides, Goodenia hederacea, Hypericum gramineum, Euchiton sphaericus, Wahlenbergia gracilis, Sorghum leiocladum, Haloragis heterophylla, Galium migrans, Sigesbeckia australiensis, Pomax umbellata, Opercularia diphylla, Galium gaudichaudii, Fimbristylis dichotoma, Dichondra* sp. A, *Carex breviculmis, Scutellaria humilis, Poranthera microphylla, Lomandra longifolia, Goodenia bellidifolia, Echinopogon ovatus.*

Introduced taxa: *Hypochaeris radicata, Conyza albida, Centaurium erythraea, Trifolium repens, Lactuca serriola, Verbena rigida, Verbena bonariensis, Secale cereale, Rubus chloocladus, Petrorhagia nanteuilii, Cirsium vulgare.*

Variability: this is predominantly a grassy and herbaceous assemblage with often a minor shrub component. However, in a few sites, particularly in more exposed positions or where soils are shallower, shrubs can become more prominent and be up to 40% cover.

Conservation status: although likely to extend from at least Inverell to Warrabah this assemblage is only reserved locally, here and in Warrabah NP and potentially Stoney Batter Ck NR. Thus, this community is not represented formally in conservation areas across its range. In addition, the number of combined hectares in reserve are likely to be low. Thus, this assemblage should be considered poorly conserved locally in terms of area, and also inadequately in terms of representation within the reserve network. Parts of this community are dominated by Yellow Box – Blakely's Red Gum and as such would be considered Endangered on the NSW *TSC* Act and the *EPB&C Act*.

Community 2: *Eucalyptus caleyi* (Caley's Ironbark) – *Eucalyptus andrewsii* (Western New England Blackbutt) Woodlands

Environmental relationships: primarily on crests and upper slopes, but also in other physiographic positions. Soils are well-drained or occasionally moist. Soil colour is usually brown, from light to grey brown or occasionally red brown, and sandy loam in texture or rarely loamy sand or loam.

Structure: primarily shrubby woodlands or open forests. Tree layer: (8–) 15–20 (–30) m tall; 20–30 (–40)% cover. Tall shrub layer: 3–10 (–12) m tall; 10–20 (–40)% cover, but usually absent. Low shrub layer: 1–3 m tall; (10–) 20–30 (–40)% cover. Understorey layer: < 1 m tall; (10–) 30–60 (–80)% cover. (Fig. 5).

Trees: *Callitris endlicheri, Eucalyptus caleyi, Eucalyptus prava, Eucalyptus andrewsii, Eucalyptus macrorhyncha, Eucalyptus quinniorum, Angophora floribunda, Eucalyptus melliodora, Eucalyptus bridgesiana.*

Shrubs: *Pultenaea* sp. G, *Cassinia quinquefaria, Leucopogon muticus, Hibbertia obtusifolia, Brachyloma daphnoides* ssp. *glabrum, Acacia neriifolia, Olearia elliptica, Lissanthe strigosa, Melichrus urceolatus, Leucopogon lanceolatus, Dodonaea viscosa* subsp. *angustifolia, Acacia penninervis, Correa reflexa, Persoonia sericea, Indigofera australis, Pultenaea spinosa, Olearia rosmarinifolia, Acacia buxifolia.*

Climbers & trailers: *Hardenbergia violacea, Glycine clandestina, Glycine tabacina, Clematis glycinoides, Billardiera scandens, Desmodium varians.*

Ground cover: *Joycea pallida, Lepidosperma laterale, Dichelachne micrantha, Lomandra multiflora, Cymbopogon refractus, Goodenia hederacea, Luzula flaccida, Macrozamia heteromera, Caladenia fuscata, Pomax umbellata, Dianella caerulea, Senecio diaschides, Wahlenbergia planiflora* subsp. *pilosa, Geranium solanderi* var. *solanderi, Patersonia sericea, Gonocarpus tetragynus, Plantago varia, Oxalis chnoodes, Dianella revoluta, Cheilanthes sieberi, Derwentia arcuata, Vittadinia cuneata, Lomandra longifolia, Carex breviculmis, Aristida vagans, Euchiton sphaericus, Themeda australis, Ranunculus lappaceus, Opercularia diphylla, Goodenia macbarroni, Derwentia arenaria, Arthropodium milleflorum, Aristida calycina, Brachyscome microcarpa, Wahlenbergia gracilis, Lomandra filiformis, Hypericum gramineum, Hydrocotyle peduncularis, Galium gaudichaudii, Dichondra repens, Crassula sieberiana, Viola betonicifolia, Veronica calycina, Poa sieberiana.*

Introduced taxa: *Hypochaeris radicata, Conyza albida, Opuntia stricta, Centaurium erythraea, Paronychia brasiliana, Arenaria leptoclados, Aira cupaniana.*

Variability: two fairly distinctive sub-assemblages are readily recognised in the field. More sheltered sites, such as on the southern side of dry shallow ridges or amongst a large collection of boulders a sub-assemblage dominated by *Eucalyptus andrewsii, E. quinniorum* and *E. macrorhyncha* occurs. The understorey is primarily dominated by *Pultenaea* sp. G in the shrub layer and *Joycea pallida* and *Austrodanthonia* spp. are more common in the ground layer. In exposed localities such as ridges or northern slopes a second sub-assemblage occurs which is dominated by *Eucalyptus caleyi, E. prava* and *E. macrorhyncha* with an understorey of *Cassinia quinquefaria* and *Leucopogon muticus* in the shrub layer and a dominance of *Cymbopogon refractus* and *Joycea pallida* in the ground layer.

Conservation status: Wall (2000) considered similar assemblages to be 64% cleared with only 2.4% of its reservation target met. This is likely to represent an overestimate of the area cleared as this type of assemblage is usually of poor agricultural quality and is often what is left in remnants. This community can be said to be reserved across its range of occurrence, but that representation is probably inadequate in terms of the area conserved.

Community 3: *Eucalyptus prava* (Orange Gum) – *Eucalyptus andrewsii* (Western New England Blackbutt) Woodlands

Environmental relationships: commonly on slopes, particularly mid-slopes, but also on crests. On well drained or rarely moist soils, which are sandy loam or loamy sand in texture. Soils are dark brown or dark grey brown in colour.

Structure: usually low woodlands or low open woodlands verging on shrublands. Tree layer: 8–18 (–25) m tall ; 10–30% cover. Tall shrub layer: absent. Low shrub layer: 1–3 m tall; (5–) 10–20% cover. Understorey layer: < 1 m tall; 20–60 (–80)% cover. (Fig. 6).

Trees: *Eucalyptus prava, Callitris endlicheri, Eucalyptus andrewsii, Eucalyptus quinniorum, Eucalyptus macrorhyncha, Eucalyptus caleyi, Eucalyptus melliodora, Angophora floribunda.*

Shrubs: *Leucopogon muticus, Pultenaea* sp. C, *Cassinia quinquefaria, Acacia penninervis, Hibbertia acicularis, Pultenaea foliolosa, Notelaea microcarpa, Monotoca scoparia, Lissanthe strigosa, Hibbertia obtusifolia, Goodenia macbarroni, Acacia neriifolia, Ozothamnus obcordatus, Olearia viscidula, Melichrus urceolatus, Leucopogon virgatus, Hibbertia* sp. 'grandiflora', *Grevillea triternata, Brachyloma daphnoides* subsp. *daphnoides.*

Climbers & trailers: *Hardenbergia violacea.*

Ground cover: *Joycea pallida, Pomax umbellata, Lomandra multiflora, Gonocarpus tetragynus, Dichelachne micrantha, Imperata cylindrica, Wahlenbergia communis, Patersonia sericea, Opercularia diphylla, Goodenia macbarroni, Dianella revoluta, Dianella caerulea, Stylidium graminifolium, Poa sieberiana, Lomandra longifolia, Lomandra filiformis, Lepidosperma laterale, Entolasia stricta, Dichelachne sieberiana.*

Introduced taxa: non-apparent.

Variability: this assemblage is highly variable in structure but is generally a low open grassy woodland. It occurs in a variety of situations, but usually in exposed situations with shallow to almost skeletal soils on the margins of rock outcrops or areas with a great deal of loose surface rock. Tall shrub layers are absent and only a sparse low shrub layer is present. Despite this the ground layer is often sparse. The greatest overall variability is how low and open the canopy is and in the level of ground cover.

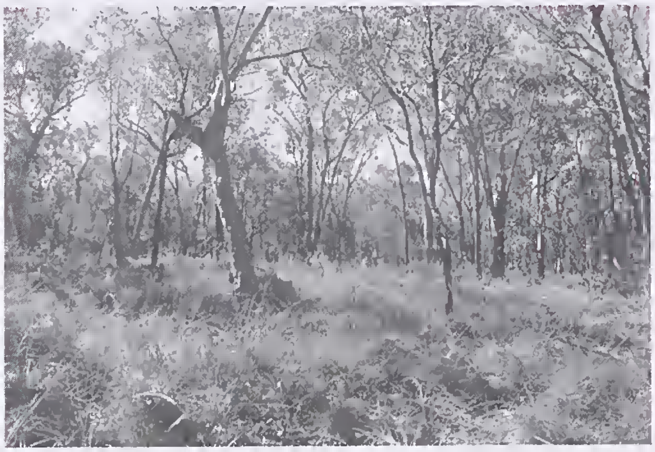

Fig. 6. Community 3: *Eucalyptus prava* and *E. andrewsii* Woodland

Conservation status: Wall (2000) considered that 58.6% of this type of assemblage has been cleared and that only 6.8% of the reservation target has been met. DeVries (2000) considered that 40% of this type of assemblage has been cleared in the Nandewar Bioregion. It is possible that the estimated amount of clearance of this type of community is overestimated, but the amount in reservation would still be minimal. Both in the strict and broad sense this community is poorly conserved across its range and the number of hectares reserved is minimal.

Community 4: *Eucalyptus dealbata* (Tumbledown Gum) – *Eucalyptus caleyi* (Caley's Ironbark) Woodlands

Environmental relationships: found usually on crests and upper slopes on well drained soils. Soils are generally sandy loam, or loamy sand or rarely loamy in texture and are grey brown to dark brown in colour. Shallow soils are most common with deep or skeletal soils being rare.

Structure: usually low open woodlands to woodlands. Tree layer: 8–15 (–25) m tall ; 10–30% cover. Tall shrub layer: absent. Low shrub layer: 1–3 m tall; 20–30 (–50)% cover. Understorey layer: < 1 m tall; 20–70% cover. (Fig. 7).

Trees: *Eucalyptus dealbata, Callitris endlicheri, Eucalyptus caleyi* subsp. *caleyi, Eucalyptus prava, Eucalyptus quinniorum, Eucalyptus macrorhyncha, Eucalyptus andrewsii, Eucalyptus albens, Brachychiton populneus, Angophora floribunda, Eucalyptus melliodora.*

Shrubs: *Cassinia quinquefaria, Olearia elliptica, Hibbertia obtusifolia, Correa reflexa, Leucopogon muticus, Acacia neriifolia, Pultenaea* sp. G, *Maytenus silvestris, Bursaria spinosa, Pultenaea* sp. C, *Notelaea microcarpa, Indigofera adesmiifolia, Melichrus urceolatus, Acacia penninervis.*

Climbers & trailers: *Desmodium varians, Glycine tabacina, Parsonsia eucalyptophylla, Clematis glycinoides.*

Ground cover: *Aristida vagans, Joycea pallida, Cymbopogon refractus, Lepidosperma laterale, Dichelachne micrantha, Lomandra multiflora, Cheilanthes distans, Aristida calycina, Wahlenbergia communis, Scleranthus biflorus, Dichondra* sp. A, *Dianella revoluta, Cheilanthes sieberi, Arthropodium milleflorum, Scleria mackaviensis, Pomax umbellata, Poa sieberiana, Austrodanthonia racemosa* subsp. *obtusata, Lomandra filiformis, Themeda australis, Lomandra longifolia, Echinopogon caespitosus, Trachymene incisa, Scutellaria humilis, Plantago varia, Panicum effusum, Oxalis chnoodes, Opercularia aspera, Luzula flaccida, Goodenia hederacea, Geranium solanderi* var. *solanderi, Desmodium brachypodum, Derwentia arenaria, Cyperus fulvus, Commelina cyanea, Carex appressa.*

Introduced taxa: *Opuntia stricta, Secale cereale, Bromus diandrus.*

Variability: few canopy species have fidelity in this assemblage. *Eucalyptus dealbata* is most commonly associated with *E. caleyi, E. prava* and *E. macrorhyncha* in one sub-assemblage on more exposed sites, with *Aristida* spp., *Joycea pallida* and *Cymbopogon refractus* common in the ground layer. In more protected sites other eucalypt taxa are also found with little fidelity, but which may commonly include *Eucallptus andrewsii* and *E. caleyi* and a ground layer commonly dominated by *Joycea pallida, Lomandra* spp. and *Cymbopogon refractus.* Both sub-assemblages have a shrub layer dominated by *Olearia elliptica* and *Cassinia quinquefaria.*

Conservation status: according to DeVries (2000) between 55–58% of similar assemblages have been cleared in the past in the Nandewar Bioregion. This assemblage in a stricter sense is likely to only occur within Ironbark NR and Warrabah NP. In both areas the distribution is limited and thus this assemblage should be considered poorly reserved both locally and across its range. The areas that include White Box – Yellow Box are considered Endangered on the NSW *TSC Act* and the *EPB&C Act.*

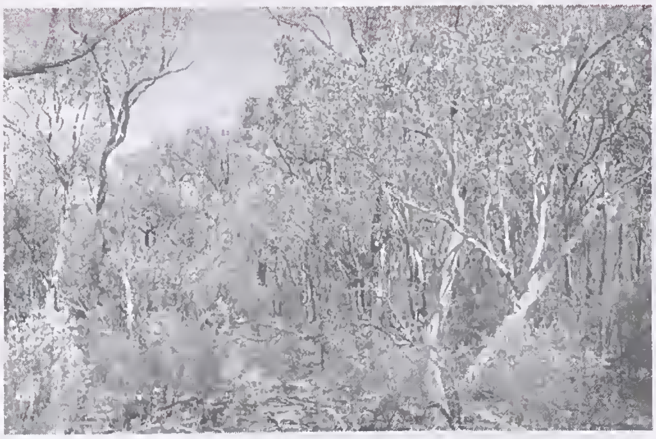

Fig. 7. Community 4: *Eucalyptus dealbata* and *Eucalyptus caleyi* subsp. *caleyi* Woodland

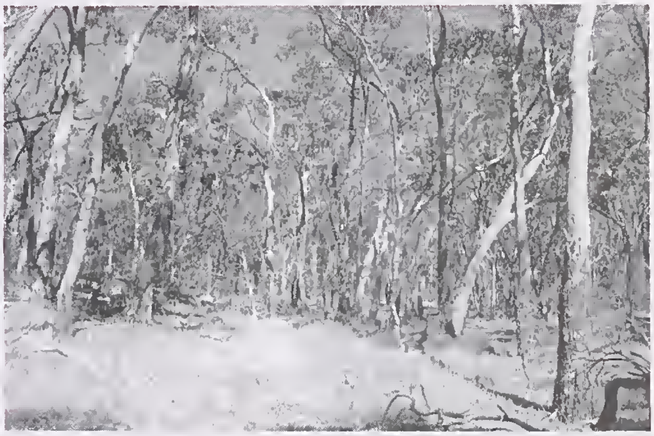

Fig. 8. Community 5: *Eucalyptus prava* and *Eucalyptus blakelyi* Woodland

Community 5: *Eucalyptus prava* (Orange Gum) – *Eucalyptus blakelyi* (Red Gum) Woodlands

Environmental relationships: found almost exclusively in open depressions but also rarely on lower slopes. Soils are usually moist but also rarely well drained or water logged. Soil texture is loam or sandy loam or rarely loamy sand or clay loam and is distinctly brown in colour.

Structure: woodlands. Tree layer: 10–25 m tall; 20–30% cover. Tall shrub layer: absent. Low shrub layer: 1–3 (–6) m tall; 10–60% cover. Understorey layer: < 1 m tall; 40–100% cover. (Fig. 8).

Trees: *Callitris endlicheri, Eucalyptus prava, Angophora floribunda, Eucalyptus blakelyi, Eucalyptus bridgesiana, Eucalyptus macrorhyncha, Eucalyptus quinniorum, Eucalyptus caleyi* subsp. *caleyi, Eucalyptus andrewsii.*

Shrubs: *Leptospermum polygalifolium, Callistemon pungens, Cassinia quinquefaria, Dodonaea viscosa* subsp. *angustifolia, Acacia neriifolia, Olearia viscidula, Olearia elliptica, Leucopogon muticus, Correa reflexa, Calytrix tetragona.*

Climbers & trailers: *Glycine clandestina, Desmodium varians, Clematis glycinoides, Rubus parvifolius.*

Ground cover: *Imperata cylindrica, Hydrocotyle peduncularis, Arthropodium milleflorum, Echinopogon caespitosus, Cymbopogon refractus, Carex gaudichaudiana, Lomandra longifolia, Dianella caerulea, Juncus subsecundus, Euchiton sphaericus, Haloragis heterophylla, Epilobium billardierianum, Juncus vaginatus, Entolasia stricta, Gonocarpus micranthus, Aristida calycina, Stellaria angustifolia, Microlaena stipoides, Luzula flaccida, Galium migrans, Dichondra repens, Carex appressa, Schoenus apogon, Geranium solanderi* var. *solanderi, Viola betonicifolia, Themeda australis, Senecio diaschides, Hypericum gramineum, Gratiola peruviana, Centipeda minima, Carex breviculmis, Wahlenbergia communis, Rumex brownii, Rhodanthe anthemoides, Ranunculus lappaceus, Lepidosperma laterale, Fimbristylis dichotoma, Dichelachne micrantha, Dianella revoluta, Acaena novae-zelandiae, Wahlenbergia gracilis, Viola hederacea, Scleranthus biflorus, Poranthera microphylla, Panicum simile, Lotus cruentus, Lotus australis, Juncus bufonius, Isolepis hookeriana, Hypericum japonicum, Arundinella nepalensis, Aristida vagans..*

Introduced taxa: *Hypochaeris radicata, Conyza albida, Trifolium repens, Rubus chloocladus, Paronychia brasiliana, Lotus uliginosus, Cirsium vulgare, Acetosella vulgaris, Vicia villosa, Verbena bonariensis, Cerastium glomeratum, Centaurium erythraea, Taraxacum officinale, Sonchus oleraceus, Plantago lanceolata, Petrorhagia nanteuilii, Paspalum dilatatum, Lactuca serriola, Axonopus affinis, Anagallis arvensis, Aira cupaniana.*

Variability: structure varies considerably in the understorey. This assemblage often occurs along drainage lines, some of which are mere ephemeral creeks and others are areas of permanent running water. The presence and density of tea-tree can change the character greatly. Areas with more permanent water, or that are damper, have a reasonably dense stand of tea-tree whereas other areas have little or none with a dense understorey of *Carex*. Some areas have been frequently burnt for green pick and are dominated by *Imperata*. In more protected localities the overstorey is taller, and may have a prominence of *E. quinniorum* and *E. bridgesiana* compared to more open situations where *E. blakelyi* and *E. prava* occur. In general, the occurrences of this assemblage are in slightly more exposed situations and sometimes shallower soils than the following Community 6.

Conservation status: similar associations are described by Wall (2000) as being nearly 60% cleared with only 1.6% of their reservation target met. These Grassy Box-Gum woodlands are usually the most intensively used for agriculture in this type of granite country and elsewhere as well. This assemblage should be considered poorly conserved across its range and potentially vulnerable and parts would be considered to be Yellow Box – Blakely's Red Gum Grassy Woodland and are endangered on the NSW *TSC Act*.

Community 6: *Eucalyptus quinniorum* (Quinn's Gum) – *Eucalyptus prava* (Orange Gum) Forests

Environmental relationships: usually in open depressions but also on lower and sometimes mid slopes. Soils are sandy loam to loam in texture and are usually deep or sometimes shallow. Soil colour is usually a dark brown, either grey or reddish.

Structure: mostly open forests but also woodlands. Tree layer: (10–) 20–30 (–40) m tall; 20–40% cover. Tall shrub layer: 5–12 m tall; 20% cover, usually absent. Low shrub layer: 1–3 m tall; 10–30 (–90)% cover, rarely absent. Understorey layer: < 1 m tall; 40–90% cover. (Fig. 9).

Trees: *Eucalyptus quinniorum, Angophora floribunda, Eucalyptus prava, Eucalyptus macrorhyncha, Eucalyptus andrewsii, Eucalyptus bridgesiana, Pittosporum undulatum, Eucalyptus blakelyi, Callitris endlicheri, Eucalyptus subtilior, Eucalyptus caleyi* subsp. *caleyi, Eucalyptus melliodora.*

Shrubs: *Olearia viscidula, Pultenaea* sp. *G, Leptospermum polygalifolium, Acacia neriifolia, Olearia elliptica, Leucopogon muticus, Hibbertia obtusifolia, Brachyloma daphnoides* subsp. *glabrum, Cassinia quinquefaria, Correa reflexa, Pultenaea campbellii, Notelaea microcarpa, Leptospermum brevipes, Persoonia sericea.*

Climbers & trailers: *Clematis glycinoides, Desmodium varians, Hardenbergia violacea, Rubus parvifolius, Glycine clandestina, Glycine tabacina, Cassytha pubescens.*

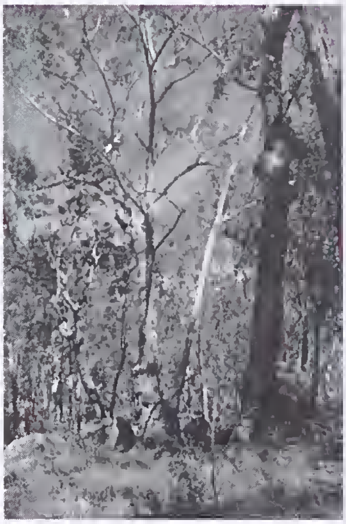

Fig. 9. Community 6: *Eucalyptus quinniorum* and *Eucalyptus prava* Forest

Ground cover: *Scleranthus biflorus, Luzula flaccida, Geranium solanderi* var. *solanderi, Lomandra longifolia, Lepidosperma laterale, Imperata cylindrica, Joycea pallida, Dichondra repens, Cymbopogon refractus, Carex breviculmis, Galium migrans, Aristida vagans, Cheilanthes sieberi, Themeda australis, Senecio diaschides, Microlaena stipoides, Dianella revoluta, Cassinia quinquefaria, Veronica calycina, Scutellaria humilis, Oxalis chnoodes, Entolasia stricta, Echinopogon caespitosus, Carex appressa, Arthropodium milleflorum, Adiantum aethiopicum, Lomandra multiflora, Dichelachne micrantha, Dianella caerulea, Caladenia fuscata, Aristida calycina, Acaena novae-zelandiae, Plantago varia, Pellaea nana, Macrozamia heteromera, Euchiton sphaericus, Ajuga australis, Wahlenbergia planiflora, Wahlenbergia gracilis, Viola betonicifolia, Solanum elegans, Pterostylis curta, Pteridium esculentum, Hydrocotyle peduncularis, Derwentia arenaria, Craspedia variabilis.*

Introduced taxa: *Hypochaeris radicata, Conyza albida, Cirsium vulgare, Rubus chloocladus, Trifolium repens, Solanum nigrum, Bidens pilosa.*

Variability: two distinct sub-assemblages are recognisable. In more exposed situations, usually on shallower soils, *Eucalyptus prava* frequently dominates with an assortment of other species such as *Eucalyptus macrorhyncha, Eucalyptus quinniorum* and *E. caleyi*. The understorey is often of *Leptospermum brevipes* and *Leucopogon muticus* with a ground layer of *Joycea pallida* and *Lomandra longifolia*. The second sub-assemblage occurs in protected localities and is dominated by *Eucalyptus quinniorum* and *Angophora floribunda* with *Eucalyptus andrewsii* and *Eucalyptus macrorhyncha*. The understorey often has a prominent layer of *Olearia elliptica* and *Olearia viscidula* and an understorey of *Imperata cylindrica* and *Cymbopogon refractus*. Two sampled localities within Ironbark also are slightly different in that they contained *Pittosporum undulatum* and a ground layer including ferns.

Conservation status: no directly synonymous assemblages are described, so the extent of this community in other reserves is hard to establish. However, it is very likely that much less than 1000 ha is reserved across its range, even if described in the broader sense. Thus, this assemblage is highly restricted in distribution and inadequately represented in the reserve network and should be considered poorly conserved.

Community 7: *Angophora floribunda* (Rough-barked Apple) – *Eucalyptus blakelyi* (Red Gum) Woodlands

Environmental relationships: usually on lower slopes, but also mid-slopes or rarely upper slopes or open depressions. Soils are usually sandy loam in texture but also may be loamy sand or clay loam. Soils are usually moist and deep and are light brown to dark brown in colour.

Structure: woodlands and open forests. Tree layer: 10–20 (–40) m tall; (10–) 20–40% cover. Tall shrub layer: 4–8 m tall; 20% cover, usually absent. Low shrub layer: 1–3 (–6) m tall; 10–30 (–70)% cover. Understorey layer: < 1 m tall; (20–) 70–90% cover. (Fig. 10).

Trees: *Angophora floribunda, Eucalyptus dealbata, Eucalyptus blakelyi, Eucalyptus melliodora, Callitris endlicheri, Eucalyptus macrorhyncha, Eucalyptus albens, Eucalyptus bridgesiana, Brachychiton populneus, Eucalyptus caleyi* subsp. *caleyi, Eucalyptus andrewsii.*

Shrubs: *Hibbertia obtusifolia, Notelaea microcarpa, Olearia viscidula, Melichrus urceolatus, Cassinia quinquefaria, Olearia elliptica, Leptospermum polygalifolium, Leptospermum brevipes, Brachyloma daphnoides* subsp. *glabrum, Acacia neriifolia, Phyllanthus subcrenulatus, Callistemon pungens, Xanthorrhoea johnsonii, Sida cunninghamii, Maytenus silvestris, Dodonaea viscosa* var. *angustifolia, Acacia implexa.*

Climbers & trailers: *Desmodium varians, Glycine tabacina, Glycine clandestina, Clematis glycinoides, Hardenbergia violacea, Glycine stenophita.*

Ground cover: *Cymbopogon refractus, Aristida calycina, Dichondra* sp. A*, Echinopogon caespitosus, Cheilanthes sieberi, Aristida vagans, Scleranthus biflorus, Geranium solanderi* var. *solanderi, Eragrostis leptostachya, Imperata cylindrica, Wahlenbergia communis, Austrodanthonia racemosa* subsp. *obtusata, Arundinella nepalensis, Microlaena stipoides, Lomandra multiflora, Chrysocephalum apiculatum, Aristida ramosa, Juncus pauciflorus, Carex appressa, Acaena novae-zelandiae, Scutellaria humilis, Rumex brownii, Oxalis chnoodes, Desmodium brachypodum, Dichelachne micrantha, Poa sieberiana, Plantago varia, Panicum effusum, Dichondra repens, Tripogon loliiformis, Lomandra longifolia, Dianella revoluta, Cyperus gracilis, Arthropodium milleflorum, Vittadinia muelleri, Sigesbeckia australiensis, Senecio diaschides, Lepidosperma laterale, Epilobium billardierianum, Commelina cyanea, Oxalis perennans, Lespedeza juncea, Joycea pallida, Hypericum gramineum, Hydrocotyle laxiflora, Gonocarpus tetragynus, Galium migrans, Fimbristylis dichotoma, Eragrostis elongata, Echinopogon ovatus, Dianella caerulea, Centipeda cunninghamii, Carex breviculmis..*

Introduced taxa: *Conyza albida, Hypochaeris radicata, Opuntia stricta, Hypochaeris glabra, Conyza bonariensis, Cyperus aggregatus, Acetosella vulgaris, Tradescantia fluminensis, Stellaria media, Sonchus oleraceus, Bidens pilosa, Verbascum thapsus, Secale cereale, Rubus chloocladus, Cirsium vulgare, Centaurium erythraea, Anagallis arvensis.*

Variability: this is a highly variable assemblage with up to three sub-assemblages, each with a highly diverse set of dominant trees with relatively low fidelity. The first sub-assemblage occurs in open and exposed sites and often is dominated by *E. albens* and *E. dealbata*

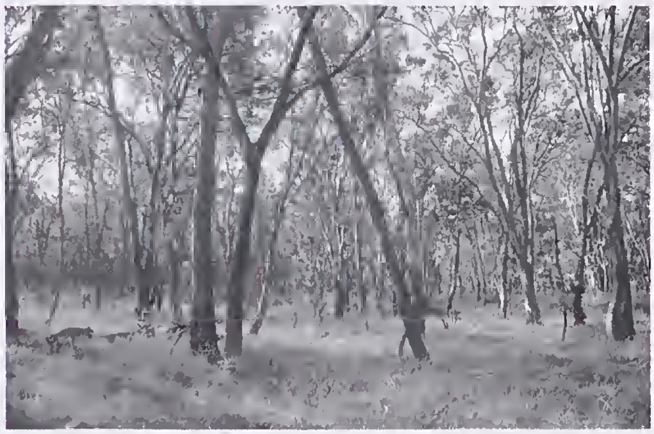

Fig. 10. Community 7: *Angophora floribunda* and *Eucalyptus blakelyi* Woodland.

with *E. melliodora* and *E. blakelyi* also associated. The understorey is of scattered *Cassinia quinquefaria* and *Notelaea microcarpa* and *Olearia viscidula*. The ground layer is often dominated by *Cymbopogon refractus*. Sites are on lower slopes with soils that are moist to well drained, loamy in texture (clay loam, loam or sandy loam) and are light to yellow brown. The second sub-assemblage is mainly dominated by *E. blakelyi* and *Angophora floribunda*, with other species such as *E. melliodora*, *E. bridgesiana* and *E. andrewsii*. The understorey often contains *Leptospermum polygalifolium* and sometimes *Notelaea microcarpa* and *Callistemon pungens*. The ground layer often contains *Imperata cylindrica*, *Lomandra longifolia* and *Arundinella nepalensis*. Soils are usually moist and sandy loam in texture, with a light to dark brown colour. The third sub-assemblage is commonly dominated by *E. melliodora* and *Angophora floribunda* with subdominant *E. blakelyi* and *E. macrorhyncha*. Understorey shrubs commonly include *Notelaea microcarpa*, *Olearia viscidula* and *Leptospermum brevipes*. The ground cover is usually of *Cymbopogon refractus* and *Aristida* spp and the sub-assemblage is usually found on mid and lower slopes on well drained soils which are sandy loam in texture and dark to grey brown in colour.

Conservation status: DeVries (2000) considered that 94% of similar assemblages within the Nandewar Bioregion have been cleared. This community type would correspond to the Endangered White Box – Yellow Box – Blakely's Red Gum listed on the *TSC Act* in most areas. This community type is represented in a number of reserves but is usually highly modified, as has occurred here in the past, and of limited extent. Thus, this community should be considered Endangered and poorly conserved both locally and across its range.

Community 8: *Casuarina cunninghamiana* (River Oak) – *Eucalyptus blakelyi* (Red Gum) – *Angophora floribunda* (Apple) Forests

Environmental relationships: restricted to open depressions or flats associated with permanent major creeks. Soils are moist to damp, sandy loam, clay loam or loamy sand in texture and are dark or yellow brown in colour and are deep.

Structure: open forests. Tree layer: 20–40 m tall; 30–60% cover. Tall shrub layer: 5–12 m tall; 10% cover, usually absent. Low shrub layer: 2–8 m tall; 20–30% cover. Understorey layer: < 1 m tall; 70–90% cover. (Fig. 11).

Trees: *Eucalyptus blakelyi*, *Casuarina cunninghamiana*, *Angophora floribunda*, *Eucalyptus bridgesiana*, *Eucalyptus macrorhyncha*, *Eucalyptus prava*, *Brachychiton populneus*.

Shrubs: *Notelaea microcarpa*, *Olearia viscidula*, *Maytenus silvestris*, *Callistemon pungens*.

Climbers & trailers: *Desmodium varians*, *Glycine clandestina*.

Ground cover: *Microlaena stipoides*, *Juncus pauciflorus*, *Imperata cylindrica*, *Dichondra repens*, *Cyperus lucidus*, *Cymbopogon refractus*, *Commelina cyanea*, *Arundinella nepalensis*, *Rumex brownii*, *Lomandra longifolia*, *Juncus vaginatus*, *Hydrocotyle peduncularis*, *Echinopogon caespitosus*, *Aristida ramosa*, *Viola hederacea*, *Viola caleyana*, *Vernonia cinerea*, *Urtica incisa*, *Scutellaria humilis*, *Scirpus polystachyus*, *Pteridium esculentum*, *Persicaria hydropiper*, *Oplismenus imbecillis*, *Isotoma fluviatilis*, *Isolepis hookeriana*, *Geranium solanderi* var. *solanderi*, *Einadia trigonos*, *Dichondra* sp. A, *Chenopodium pumilio*, *Carex appressa*, *Adiantum aethiopicum*.

Introduced taxa: *Conyza albida*, *Cyperus aggregatus*, *Modiola caroliniana*, *Hypochaeris radicata*, *Conyza bonariensis*, *Stellaria media*, *Solanum nigrum*, *Rubus chloocladus*, *Ciclospermum leptophyllum*, *Bidens pilosa*, *Anagallis arvensis*.

Variability: only three sites were placed within this assemblage thus only minimal variation can be described. The most obvious difference between sites is the occurrence or not of *Casuarina cunninghamiana*. This species is the most readily recognisable member of this assemblage, however the fringing 'floodplain' or areas of previous stream bank flow, where vegetation is without River Oak, also falls into the circumscription of this assemblage. Within the main creek channel many species occur, particularly wetland taxa such as *Carex*, that do not occur in the fringing vegetation, which often is dominated by *Imperata cylindrica*.

Conservation status: DeVries (2000) considered that 79% of similar assemblages have been cleared in the Nandewar Bioregion. This community probably occurs thoughout the north western slopes and into western south east Queensland. Areas within the current reserve network are very small, and in most situations are highly disturbed or invaded by exotic species. This community should be considered as poorly reserved across its range with much that is reserved being of poor quality.

Community 9: *Calytrix tetragona* (Fringe Myrtle) – *Ozothamnus obcordatus* (Daisy Bush) Open Shrublands

Environmental relationships: restricted to rock platforms and outcrops. Soils are well drained, sandy peat to sandy loam or loam. They are black to brown or red brown in colour and skeletal.

Structure: usually open shrublands but also woodlands, herbfields or grasslands. Tree layer: 5–12 m tall ; 10 (–30)% cover, usually absent. Tall shrub layer: 2–4 m tall; 10% cover, rarely present. Low shrub layer: 1–3 m tall; 10 (–30)% cover. Understorey layer: < 1 m tall; (10–) 20 (–30)% cover. (Fig. 12).

Trees: *Callitris endlicheri*, *Eucalyptus prava*, *Eucalyptus dealbata*.

Shrubs: *Calytrix tetragona*, *Ozothamnus obcordatus*, *Homoranthus bornhardtiensis*, *Prostanthera nivea*, *Leptospermum novae-angliae*,

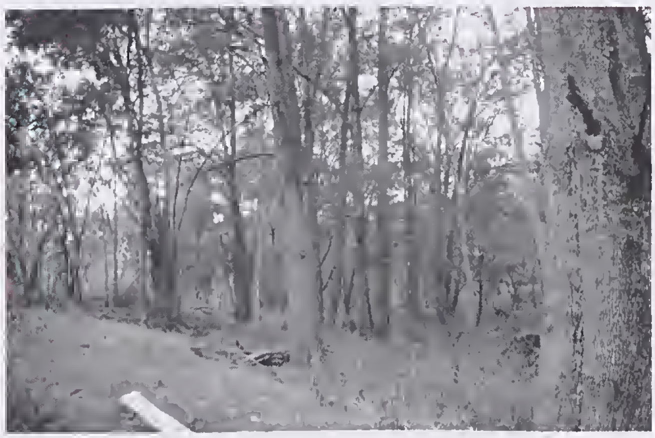

Fig. 11. Community 8: *Casuarina cunninghamiana* and *Eucalyptus blakelyi* Forest.

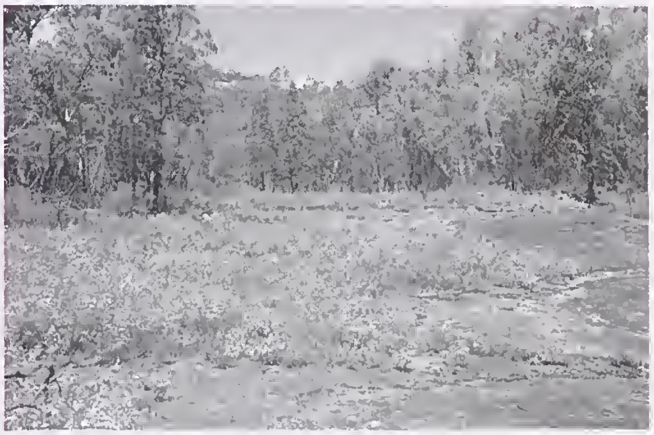

Fig. 12. Community 9: *Calytrix tetragona* and *Ozothamnus obcordatus* Open Shrubland.

Leucopogon muticus, Acacia neriifolia, Boronia anethifolia, Acacia triptera, Cyphanthera albicans, Acacia viscidula, Kunzea parvifolia, Hibbertia sp. 'grandiflora', *Cryptandra amara, Acacia cheelii, Mirbelia pungens, Leptospermum brevipes, Hibbertia cistoidea.*

Climbers & trailers: *Cassytha pubescens.*

Ground cover: *Tripogon loliiformis, Lepidosperma laterale, Stypandra glauca, Gonocarpus tetragynus, Cheilanthes sieberi, Cyperus secubans, Thelionema grande, Brachyscome stuartii, Isotoma anethifolia, Crassula sieberiana, Trachymene incisa, Pomax umbellata, Austrodanthonia laevis, Aristida calycina, Cymbopogon refractus, Gonocarpus teucrioides, Fimbristylis dichotoma, Lobelia gracilis, Gonocarpus oreophilus, Entolasia stricta, Digitaria ramularis, Aristida vagans, Vittadinia muelleri, Ophioglossum lusitanicum, Laxmannia gracilis, Joycea pallida, Isotoma axillaris, Drosera burmannii, Dichelachne micrantha, Cheilanthes distans, Calandrinia eremaea, Brachyscome nova-anglica, Austrodanthonia monticola, Aristida ramosa, Actinotus helianthi.*

Variability: structurally highly variable. Two distinct sub-assemblages occur which are largely based on changes in herbaceous vegetation, one sub-assemblage appears to be restricted to peaty black soils which are associated with colder, wetter and more protected localities, and the other has sandy loam to loamy brown to red brown soils. The latter are usually in more exposed drier localities. Overall, outcrop communities are highly structured by stochastic distributions and frequent sporadic colonisation and extinction and hence they can appear structurally very dissimilar even when in close proximity to each other. The occasional tree can be present giving a low open woodland appearance. Shrubs can be prominent and dense in some localities, such as *Leptospermum brevipes* or *L. novae-angliae* giving a dense tall heath appearance. However, overall a large enough number of shared species occur, including many outcrop endemics, that enable delineation of the assemblage based purely on floristics.

Conservation status: Hunter & Clarke's (1998) community 7f within Element 7 is directly synonymous with this assemblage. Element 7 was considered be under-represented within the reserve network as a whole. This community is restricted to *Bornhardtia* and Ironbark and is one of only three communities out of a total of eight within this Element to be reserved. Despite the Element as a whole being under-represented, the extensive outcrop areas within Ironbark and *Bornhardtia* mean that locally this community is adequately reserved. This does not mean that further inclusions of this assemblage would not be important as Hunter (2000a, 2002c, 2003c) has shown the nature of naturally fragmented ecosystems means that any addition to the reserve network would significantly increase species richness and resilience of this assemblage.

Community 10: *Homoranthus bornhardtiensis* Open Shrublands

Environmental relationships: restricted entirely to skeletal soils on rock outcrops in gravel basins and within the cracks and fissures on the outcrops. Sometimes associated with the immediate fringe of flat rocks around inselbergs and near-surface fugitive outcrops.

Structure: primarily shrublands but occasionally grasslands, herbfields or low open woodlands. Tree layer: 6–15 m tall; 10% cover, usually absent. Tall shrub layer: 3–10 m tall; 10–20% cover, usually absent. Low shrub layer: 1–3 m tall; 5–20% cover. Understorey layer: < 1 m tall; 20–40 (–80)% cover. (Fig. 13).

Trees: *Callitris endlicheri, Eucalyptus prava, Eucalyptus dealbata, Eucalyptus caleyi* subsp. *caleyi, Eucalyptus blakelyi.*

Shrubs: *Homoranthus bornhardtiensis, Cassinia quinquefaria, Leucopogon muticus, Calytrix tetragona, Melichrus urceolatus, Hibbertia obtusifolia, Acacia neriifolia, Ozothamnus obcordatus, Pultenaea* sp. G., *Olearia elliptica, Notelaea microcarpa, Leptospermum brevipes, Grevillea triternata, Mirbelia pungens, Brachyloma daphnoides* subsp. *glabrum.*

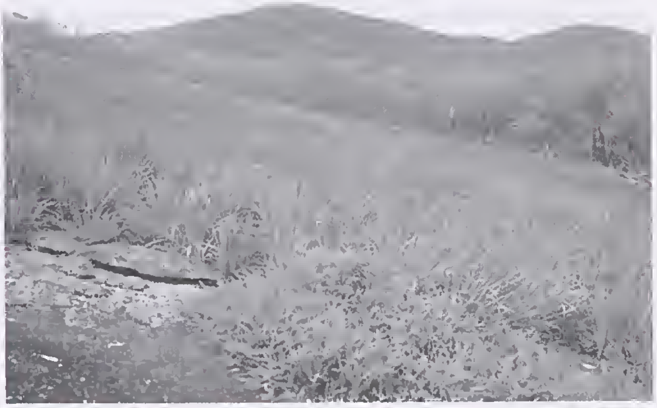

Fig. 13. Community 10: *Homoranthus bornhardtiensis* Open Shrubland.

Climbers & trailers: *Glycine tabacina, Desmodium varians.*

Ground cover: *Tripogon loliiformis, Cymbopogon refractus, Cheilanthes sieberi, Aristida calycina, Fimbristylis dichotoma, Pomax umbellata, Dichelachne micrantha, Arthropodium milleflorum, Thelionema grande, Chrysocephalum apiculatum, Cheilanthes distans, Trachymene incisa, Joycea pallida, Hypericum gramineum, Eragrostis elongata, Dianella caerulea, Aristida vagans, Aristida ramosa, Wurmbea biglandulosa, Lepidosperma laterale, Goodenia macbarroni, Cyperus fulvus, Chrysocephalum semipapposum, Austrodanthonia racemosa* ssp. *obtusata, Vittadinia cuneata, Triptilodiscus pygmaeus, Plantago varia, Goodenia hederacea, Gonocarpus teucrioides, Drosera peltata, Cyperus secubans, Crassula sieberiana, Commelina cyanea, Brachyscome multifida, Wahlenbergia planiflora* subsp. *pilosa, Vittadinia muelleri, Senecio lautus, Poa sieberiana, Panicum effusum, Murdannia graminea, Luzula flaccida, Laxmannia compacta, Hydrocotyle peduncularis, Haloragis heterophylla, Gonocarpus tetragynus, Galium migrans, Eragrostis leptostachya, Entolasia stricta, Digitaria breviglumis, Cymbopogon obtectus, Brachyscome nova-anglica, Actinotus helianthi.*

Introduced taxa: *Hypochaeris radicata, Opuntia stricta, Aira cupaniana.*

Variability: highly variable in structure. *Homoranthus bornhardtiensis*, though highly abundant in many sites, is not ubiquitous. Two sub-assemblages are apparent, the first of which usually does not have this species as a component, or at least not as a dominant. This first sub-assemblage occurs on loam or sandy loam soils that are usually yellow brown in colour. The second sub-assemblage is usually dominated by *Homoranthus bornhardtiensis* and occurs on sandy loam or loamy sand soils that are chocolate to orange brown in colour. In some situations grasses predominate, giving the structure of a small grassland, or herbfield if grasses are absent.

Conservation status: Community 7f within Element 7 of Hunter and Clarke (1998) is directly synonymous with this assemblage, thus the comments made in the previous community are relevant to this one also.

Community 11: *Leptospermum polygalifolium* (Tea-tree) Wetland

Environmental relationships: restricted to permanently waterlogged sites.

Structure: woodlands to herbfields. Tall shrub layer: 2–5 m tall; 40% cover. Low shrub layer: 1–2 m tall; 10% cover. Understorey layer: > 1 m tall; 100% cover. (Fig. 14).

Trees: none apparent.

Shrubs: *Leptospermum polygalifolium, Hakea microcarpa, Callistemon pungens.*

Climbers & trailers: none apparent.

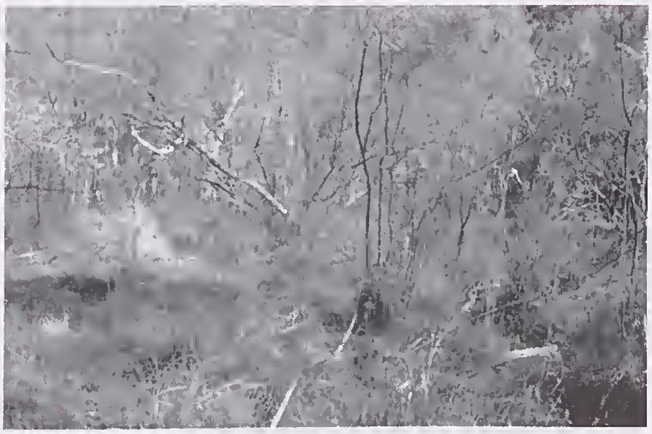

Fig. 14. Community 11: *Leptospermum polygalifolium* Wetland.

Ground cover: *Stellaria angustifolia, Ranunculus* sp. *A, Phragmites australis, Gonocarpus micranthus, Geranium solanderi* var. *grande, Epilobium billardierianum, Baloskion stenocoleum, Schoenus apogon, Eryngium vesciculosum, Juncus vaginatus, Juncus fockei, Hydrocotyle peduncularis, Carex gaudichaudiana, Arthropodium milleflorum, Rhynchospora brownii.*

Introduced taxa: *Trifolium repens, Lotus uliginosus, Axonopus affinis.*

Variability: only one formal site sampled this assemblage therefore, community variability cannot be adequately discussed. However, the assemblage is likely to be very stochastic both in temporal and spatial terms. Differences in extent of water-logging and duration will significantly affect what species are present in the long term and also how extensive the community is. Some areas have extensive and dense *Phragmites* stands and *Leptospermum polygalifolium* may or may not be present as a significant feature.

Conservation status: this assemblage only occurs in small areas of less than one hectare, with a sporadic and isolated distribution. It is under significant threat from various land uses and by feral animals, particularly pigs, and weeds. This type of assemblage should be considered vulnerable and poorly conserved, both locally and across its range if it is synonymous with more widespread associations.

Discussion

Phytogeography

Based on analysis and mapping, the two conservation areas (Ironbark and *Bornhardtia*) capture significantly different proportions of communities, and a number of the communities are confined to one or the other. Overall the two conservation areas complement each other. For example, Community 2 is entirely restricted to *Bornhardtia* where it is very common, Communities 1, 5, 6 and 9 have the bulk of their distribution within *Bornhardtia,* while Communities 4, 7, and 8 only occur in Ironbark. The remaining Communities 3, 10 and 11 are common in both areas.

Community 1 in broad terms is likely to occur from south of Inverell and Howell area extending south to the eastern and higher altitude areas of Warrabah NP but no direct correlates are described in the literature. Unlike some other assemblages described herein, *Olearia* species do not dominate, and unlike Community 2 *Pultenaea* sp. *G* is usually absent or rare in the shrub layer.

In broad circumscription, Communities 2 and 3 are likely to occur from the Sundown area of Queensland as far south as Warrabah, but they are likely to be more common from south of Goonoowiggal to Warrabah and as far east as Single NP and the Basin NR. In the strictest sense, these communities only occur from the study area south to the high altitude eastern parts of Warrabah National Park and surrounds. Community 2 has a very distinct shrub layer characterised by *Pultenaea, Cassinia* and *Leucopogon,* with only a moderately dense grassy understorey, which is in contrast to Community 1.

White Box – Yellow Box – Red Gum occurs within Community 4. This mix is very limited in distribution within Ironbark and is known only from small intrusions of differing lithology along the western boundary of the Nature Reserve. In general, this assemblage had been selectively cleared for grazing.

No directly synonymous assemblages to Communities 4 or 5 are described in the literature. These assemblages are probably included within much more widespread Blakely's Red Gum Associations in broad scale mapping, or under Grassy Box-Red Gum Alliances. Community 4 in the broad sense is likely to occur from west of Tenterfield to Warrabah, but in the strict sense only in more western areas of Copeton Dam to western areas of Warrabah. Community 5 and synonymous assemblages are likely to be common along the western side of the tablelands and along the slopes from over the Queensland border south to northern Victoria. However, in the stricter sense Community 5 is likely to be largely restricted to the study area, with small occurrences as far north as west of Tenterfield and as far south as Warrabah.

The most prominent tree within Community 6 is the rare *Eucalyptus quinniorum,* which has a very restricted distribution from Ironbark to Warrabah NP, with some isolated stands within the Bendemeer and Moonbi areas. A broadly similar assemblage occurs on the eastern fall of Mt Kaputar, which is dominated by *Eucalyptus volcanica,* a close relative of *Eucalyptus quinniorum* (Hunter & Alexander 2000). This assemblage in the broad sense is thus likely to occur from the eastern fall of Mt Kaputar east to Ironbark and Stoney Batter Creek Nature Reserve and as far south as Warrabah, with potential extension as far south as Bendemeer and higher altitude parts of the Moonbi Ranges.

Community 7 most closely resembles the widespread Yellow Box – Red Gum alliance that is found from south eastern Queensland to the northern parts of Victoria along the western margin of the tablelands and along the western slopes. This variant as described here is likely to be more or less restricted to the areas west of Glen Innes to the Tamworth region.

Casuarina cunninghamiana communities are widespread in New South Wales. Beadle (1981) states that *Casuarina cunninghamiana* communities fringing rivers are common from southern New South Wales to Cape York and even to Arnhem Land. However, there are no regularly associated species. It appears that although riverine communities similar to Community 8 occur throughout this part of the state they have been rarely sampled or described.

Communities 9 and 10 would both be placed within Element 7: Western New England Shrublands and Herbfields by Hunter and Clarke (1998). Both assemblages in broad circumscription occur from Sundown NP in Queensland to Bendemeer in New South Wales and potentially west to Mt Kaputar, excluding the Howell–Copeton Dam area.

The most synonymously described assemblage to Community 11 occurs in Single National Park in similar situations (Clarke et al. 2000). The distribution of this type of assemblage is likely to be very small and highly scattered, with stands usually less than 1 ha in size.

It appears that some of the assemblages described here, particularly those that could be described as part of the box–red gum alliances have broad affinities with similar associations occurring from south-eastern Queensland to as far south as northern Victoria. Most of the assemblages may in broad circumscription be similar to others occurring from the Sundown area of south-eastern Queensland to Tamworth. Most assemblages, though, appear to be highly restricted with greatest affinities to others occurring from the south of Inverell to Warrabah NP, thus supporting Province 16 (Eastern Nandewars), of Morgan and Terry (1999).

In broad terms of floristic affinities, the taxa within the study area indicate a cross-over between the North Western Slopes and the Northern Tablelands floras. 90% of all species found are also recorded for the North Western Slopes. This is not unexpected as the western and southern boundaries of the study area fall on the boundary between the New England Tablelands and Nandewar Bioregions. 80% of all species found are also recorded for the North Coast and Central Coast regions of New South Wales, indicating that in general, floristic affinities are shared with warmer areas such as coastal regions before they are shared with other tablelands areas.

Species richness

477 taxa were found within Ironbark Nature Reserve and the *Bornhardtia* Voluntary Conservation Agreement. In terms of average site species richness on a 0.04 ha site the study area is medial (35 per 0.04 ha) and is similar to that found at Gibraltar Range and Arakoola National Parks and Burnt Down Scrub and Curry's Gap Nature Reserves (Hunter *in review*; Hunter & Harrison 2002, Sheringham & Hunter 2002). Kings Plains National Park (51 per 0.04 ha) has the highest recorded richness in the north east of NSW (Hunter 2000b) while Gibraltar Nature Reserve (26 per 0.04 ha) (Hunter 2002b) has the lowest.

Conservation issues

Strategically the location of Ironbark and *Bornhardtia* conservation areas is important as they are within a 13 075 ha little developed vegetated remnant (DeVries 2000) that is currently under pressure for further clearing for grazing. Morgan and Terry (1999) considered the Eastern Nandewars (Province 16), of which the study area is included, to be at a critical stage of development where many ecosystem functions may be lost if development were to increase in the region.

More generally within the New England Tableland Bioregion, these conservation areas are of importance, since approximately 60% of its woody vegetation has been cleared (Benson 1999). Temperate eucalypt woodlands are amongst the most poorly conserved and threatened ecosystems in Australia, having borne the brunt of agricultural development for well over 150 years (Yates & Hobbs 2000). Tree cover has been reduced to only 15% of its original cover on the slopes of the Namoi Catchment (DeVries 2000). Dieback is a significant problem in the Namoi Catchment, particularly in the Tablelands areas and along watercourses (DeVries 2000). Severe soil damage is likely if current development practices continue (Morgan & Terry 1999) and at present soil structure decline is moderate to severe over 35% of the Namoi catchment (DeVries 2000). Most of the developed areas are on acid soils, and leached nutrients from the overuse of nitrogenous fertilisers and introduced legumes are causing problems in the Namoi River (Morgan & Terry 1999). In addition, the Namoi Catchment is a major source of phosphorus to the Barwon-Darling River (DeVries 2000). The riparian vegetation of most creeks in the upper catchment of the Namoi River is in poor condition because of grazing pressure and clearing which is usually extended to creek banks (DeVries 2000).

Throughout both conservation areas grassy White Box – Yellow Box – Blakely's Red Gum Woodlands occur. This community is listed as Endangered under the NSW *Threatened Species Conservation Act*. In addition, Grassy White Box Woodlands are considered Endangered on the Federal *Environmental Protection and Biodiversity & Conservation* Act. Areas of Grassy White Box Woodlands occur within Ironbark Nature Reserve.

In terms of the communities as circumscribed here, none are adequately represented in the conservation network. Communities 2, 3, 9 and 10 are potentially conserved adequately within the local region but are poorly conserved across their range. Community 7 is potentially endangered and Communities 4, 8 and 11 are possibly vulnerable.

Quality is often not considered adequately in discussion of representation within conservation areas, yet this is as important as the capture of assemblages (Hunter 2003a). One of the more significant features of both conservation areas are sections that have had minimal European disturbance and which contain over mature trees. Such areas are often termed 'old growth' and examples of this quality occur across all the woodland assemblages described here.

At present, the most significant threats to these assemblages are pigs and stray cattle. Pigs in particular have caused extensive damage in creek and gully areas and on rock outcrops.

Outcrop endemic taxa are susceptible to browsing by goats (Hunter 2003b), which have degraded some outcrop vegetation significantly.

38 species were considered of conservation significance within the Ironbark and *Bornhartia* conservation areas. Two of these are also listed on the NSW *TSC Act*: one as Vulnerable and one as Endangered and 6 have been reported under the RoTAP criteria (Briggs & Leigh 1996). These include: *Homoranthus bornhardtiensis* (*TSC* Endangered), *Goodenia macbarronii* (*TSC* Vulnerable; 3VC-), *Callistemon pungens* (3RCa), *Derwentia arenaria* (3RCa), *Eucalyptus quinniorum* (3RCa), *Thelionema grande* (3RCa), *Zieria odorifera* (3RCi), and *Pultenaea campbellii* (3K). *Thelionema grande* is at its southernmost distributional limit within *Bornhartia*. Two of these species, *Eucalyptus quinniorum* and *Homoranthus bornhardtiensis*, are thought to be largely restricted to the study area; both have their type localities within *Bornhartia*. Many of the species of significance are outliers from other regions. In particular, a number of species associated with vine thickets and western dry rainforest were found in low numbers, particularly in protected gullies. Thirty species were thought to be at or near their geographic limits or were considered as significant due to being locally or regionally rare. These taxa are: *Acacia cheelii, Acacia montana, Alectryon subdentatus, Baloskion stenocoleum, Cassine australis, Centrolepis strigosa, Cymbidium canaliculatum, Cyperus secubans, Cyphanthera albicans, Geranium solanderi* subsp. *grande, Haloragis serra, Hibbertia* sp., *Jasminum sauvissimum, Lilaeopsis polyantha, Lomandra* sp., *Lyperanthus suaveolens, Mirbelia speciosa, Olearia erubescens, Ophioglossum latiusculum, Parsonsia eucalyptophylla, Pelargonium australe, Pittosporum undulatum, Portulaca bicolor, Psydrax odoratum, Psilotum nudum, Pultenaea* sp. *G, Sida cunninghamii* and *Viola caleyana*.

Conclusion

Ironbark Nature Reserve and *Bornhardtia* Voluntary Conservation Area complement each other in terms of the species found and the communities described. A number of species and some of the communities are only found in one or other of the conservation areas but not both. Eight nationally significant flora species and up to 39 locally significant flora species occur in these conservation areas. At least one community is listed as Endangered on the NSW *TSC* Act, another is listed on the *EPB&C* Act; all assemblages described are inadequately reserved across their range. Many areas exist that are minimally disturbed by Europeans and constitute Old Growth, although past clearing and grazing has occurred in more accessible areas. The representation of old growth woodlands across many vegetation assemblages is as important a feature of these conservation areas as are the endangered species and communities.

The study area represents a crossover of the floras of the NSW slopes and tablelands, and is a highlighted significant remnant within a major north-south western regional corridor. The region is at a critical stage of development where further degradation will cause significant ecological and biodiversity changes to the region.

The conservation areas alone (total area 2307 ha) are not large enough to ensure continued ecosystem processes or the long-term viability of all species. Addition of lands to the Nature Reserve, or the incorporation of lands under conservation agreements around these areas is needed to ensure the values within the study area.

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Appendix: Flora of Ironbark Nature Reserve and the *Bornhardtia* Voluntary Conservation Agreement.

Taxa found within the survey sites are scored according to their occurrence in each of the 11 communities defined. Some taxa were found in previous surveys or opportunistically (0) and therefore are not assigned to a specific community.

1 = Red Stringybark – Red Gum Woodlands,
2 = Caley's Ironbark – Western New England Blackbutt Woodlands,
3 = Orange Gum – Western New England Blackbutt Woodlands,
4 = Tumbledown Gum – Caley's Ironbark Woodlands,
5 = Orange Gum – Red Gum Woodlands,
6 = Quinn's Gum – Orange Gum Forests,
7 = Rough-barked Apple – Red Gum Woodlands,
8 = River Oak – Red Gum – Rough Barked Apple Forests,
9 = Fringe Myrtle – Daisy Bush Open Shrublands,
10 = *Homoranthus* Open Shrublands,
11 = Tea-tree Wetlands.

* denotes introduced taxa. Nomenclature follows Harden 1990–93.

PTERIDOPHYTES & ALLIES

Adiantaceae	
Adiantum aethiopicum	5, 6, 7, 8
Adiantum hispidulum	6
Aspleniaceae	
Asplenium flabellifolium	4, 6
Pleurosorus subglandulosus	0
Blechnaceae	
Blechnum wattsii	0
Doodia aspera	6
Doodia caudata	0
Dennstaedtiaceae	
Histiopteris incisa	6
Hypolepis glandulifera	0
Pteridium esculentum	2, 6, 7, 8
Grammitaceae	
Grammitis billardieri	0
Ophioglossaceae	
Ophioglossum latiusculum	9
Polypodinaceae	
Pyrrosia rupestris	0
Psilotaceae	
Psilotum nudum	2
Sinopteridaceae	
Cheilanthes distans	2, 4, 9, 10
Cheilanthes sieberi subsp. *sieberi*	1, 2, 3, 4, 5, 6, 7, 9, 10
Pellaea nana	2, 4, 6
Pellaea paradoxa	6

CYCADS

Zamiaceae	
Macrozamia heteromera	1, 2, 3, 6, 10

CONIFERS

Cupressaceae	
Callitris endlicheri	1, 2, 3, 4,5, 6, 7, 9, 11

MONOCOTYLEDONS

Anthericaceae	
Arthropodium milleflorum	1, 2, 4, 5, 6, 7, 8, 9, 10, 11
Arthropodium sp. *A*	5
Laxmannia compacta	3, 4, 5, 9, 10
Tricoryne elatior	1, 2

Asphodelaceae	
Bulbine bulbosa	0
Centrolepidaceae	
Centrolepis strigosa subsp. *strigosa*	0
Colchicaceae	
Wurmbea biglandulosa	1, 2, 6, 10
Commelinaceae	
Commelina cyanea	4, 7, 8, 9, 10
Murdannia graminea	1, 5, 7, 10
Cyperaceae	
Carex appressa	1, 4, 5, 6, 7, 8
Carex breviglumis	1, 2, 5, 6, 7
Carex gaudichaudiana	1, 5, 6, 7, 8, 11
**Cyperus aggregatus*	7, 8
Cyperus bifax	0
Cyperus fulvus	4, 10
Cyperus gracilis	1, 6, 7, 9
Cyperus lucidus	8
Cyperus sanguinolentus	5
Cyperus secubans	2, 9, 10
Cyperus sphaeroides	5
Eleocharis pusilla	5
Eleocharis sphacelata	0
Fimbristylis dichotoma	1, 5, 7, 9, 10
Gahnia aspera	2, 3, 4, 5, 10
Isolepis hookeriana	5, 8
Lepidosperma gunnii	2
Lepidosperma laterale	1, 2, 3, 4, 5, 6, 7, 9, 10
Rhynchospora brownii	11
Schoenus apogon	1, 2, 5, 6, 11
Scirpus polystachyus	8
Scleria mackaviensis	4
Haemodoraceae	
Haemodorum planifolium	0
Hydrocharitaceae	
Vallisneria gigantea	0
Hypoxidaceae	
Hypoxis hygrometrica	7
Iridaceae	
Patersonia sericea	1, 2, 3
Sisyrinchium sp. *A*	0
Juncaceae	
**Juncus bufonius*	5, 7
Juncus continuus	0
Juncus fockei	5, 11
Juncus holoschoenus	0
Juncus pauciflorus	6, 7, 8
Juncus remotiflorus	0
Juncus subglaucus	0
Juncus subsecundus	5, 6
Juncus usitatus	1, 5
Juncus vaginatus	1, 5, 6, 7, 8, 11
Luzula flaccida forma *B*	1, 2, 4, 5, 6, 7, 10
Juncaginaceae	
Triglochin multifructum	5
Lomandraceae	
Lomandra confertiflora subsp. *pallida*	1
Lomandra filiformis subsp. *filiformis*	1, 2, 3, 4, 6, 7
Lomandra longifolia	1, 2, 3, 4, 5, 6, 7, 8, 10
Lomandra multiflora	1, 2, 3, 4, 5, 6, 7, 8, 10
Lomandra sp. aff. *cylindrica*	1, 6
Luzuriagaceae	
Eustrephus latifolius	5, 6
Orchidaceae	
Acianthus collinus	0
Acianthus exsertus	0
Caladenia fimbriatus	0
Caladenia fuscata	1, 2, 5, 6, 9, 10

Calochilus gracillimus	0
Corybas fimbriatus	2, 6
Cymbidium canaliculatum	0
Dipodium variegatum	1
Diuris abbreviata	2, 9
Dockrillia linguiforme	0
Lyperanthus suaveolens	0
Microtis unifolia	0
Pterostylis coccina	0
Pterostylis curta	1, 2, 5, 6
Pterostylis longiflora	2
Pterostylis mutica	1, 6, 10
Pterostylis parviflora	2, 5
Pterostylis rufa	1, 9
Spiranthes sinensis subsp. *australis*	0
Thelymitra pauciflora	2
Phormiaceae	
Dianella caerulea subsp. *caerulea*	1, 2, 3, 4, 5, 6, 7, 10
Dianella revoluta var. *revoluta*	1, 2, 3, 4, 5, 6, 7, 8
Stypandra glauca	9, 10
Thelionema grande	2, 5, 9, 10
Poaceae	
Aira cupaniana	2, 5, 10
Aristida calycina var. *calycina*	1, 2, 3, 4, 5, 6, 7, 9, 10
Aristida jerichoensis var. *subspinulifera*	0
Aristida ramosa var. *speciosa*	4, 7, 8, 9, 10
Aristida vagans	1, 2, 3, 4, 5, 6, 7, 9, 10
Arundinella nepalensis	5, 7, 8, 10
Austrodanthonia fulva	0
Austrodanthonia laevis	1, 2, 6, 9
Austrodanthonia monticola	9
Austrodanthonia racemosa var. *obtusata*	2, 4, 6, 7, 10
Austrostipa ramosissima	4
Austrostipa scabra	7
Austrostipa setacea	1, 4, 5, 6, 7, 10
Austrostipa verticillata	1
**Axonopus affinis*	5, 11
Bothriochloa decipiens	5, 7
**Briza minor*	0
**Bromus diandrus*	4
Chloris truncata	4
Cleistochloa rigida	2
Cymbopogon obtectus	10
Cymbopogon refractus	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Deyeuxia mckiei	0
Dichelachne crinita	4
Dichelachne micrantha	1, 2, 3, 4, 5, 6, 7, 9, 10
Dichelachne sieberiana	3, 5
Digitaria breviglumis	7, 10
Digitaria ramularis	4, 5, 7, 9
Echinopogon caespitosus var. *caespitosus*	1, 2, 4, 5, 6, 7, 8
Echinopogon cheelii	7
Echinopogon ovatus	1, 5, 7
Entolasia stricta	2, 3, 5, 6, 7, 9, 10
Eragrostis brownii	0
Eragrostis elongata	1, 4, 7, 9, 10
Eragrostis lacunaria	1
Eragrostis leptostachya	1, 4, 5, 7, 10
Festuca asperula	10
Imperata cylindrica var. *major*	1, 3, 4, 5, 6, 7, 8
Joycea pallida	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Microlaena stipoides var. *stipoides*	1, 3, 5, 6, 7, 8
Notodanthonia longifolia	9
Oplismenus aemulus	4, 5, 6, 8
Panicum effusum	1, 2, 4, 7, 10
Panicum simile	2, 5, 7
**Paspalum dilatatum*	5
Pennisetum alopecurioides	5
Phragmites australis	5, 11
Poa sieberiana	1, 2, 3, 4, 6, 7, 10
**Secale cereale*	1, 4, 7

Sorghum leiocladum	1, 2, 4, 5, 7
Sporobolus creber	10
Themeda australis	1, 2, 3, 4, 5, 6
Tripogon loliiformis	1, 2, 4, 7, 9, 10
Restionaceae	
Baloskion stenocoleum	5, 11
Xanthorrhoeaceae	
Xanthorrhoea johnsonii	1, 2, 4, 6, 7
DICOTYLEDONS	
Amaranthaceae	
Alternanthera denticulata	8
Apiaceae	
Actinotus helianthi	3, 9, 10
**Ciclospermum leptophyllum*	8
Daucus glochidiatus	1, 7
Eryngium visculosum	11
**Foeniculum vulgare*	0
Hydrocotyle geraniifolia	6
Hydrocotyle laxiflora	5, 6
Hydrocotyle peduncularis	1, 2, 5, 6, 8, 10, 11
Lilaeopsis polyantha	0
Trachymene incisa	2, 4, 9, 10
Apocynaceae	
Parsonsia eucalyptophylla	4
Araliaceae	
Astrotricha longifolia	0
Asclepiadaceae	
**Gomphocarpus fruticosus*	0
Asteraceae	
Bidens pilosa	6, 7, 8
Brachyscome aculeata	0
Brachyscome microcarpa	1, 2
Brachyscome multifida var. *multiflora*	1, 2, 3, 5, 10
Brachyscome nova-anglica	9, 10
Brachyscome stuartii	9
Bracteantha bracteata	2
Calotis cuneifolia	2
Calotis lappulaceae	7
Cassinia quinquefaria	1,2, 3, 4, 5, 6, 7, 9, 10
Cassinia uncata	1
Centipeda cunninghamii	7
Centipeda minima var. *minima*	5
Chrysocephalum apiculatum	1, 2, 6, 7, 10
Chrysocephalum semipapposum	1, 2, 3, 10
**Cirsium vulgare*	1, 5, 6, 7
**Conyza albida*	1, 2, 5, 6, 7, 8
**Conyza bonariense*	7, 8
Craspedia variabilis	1, 2, 5, 6
Cymbonotus lawsonianus	1, 7
Euchiton involucratus	0
Euchiton sphaericus	1, 2, 5, 6, 7
Glossogyne tannensis	4
Hyalosperma semisterile	9
**Hypochaeris glabra*	7, 9
**Hypochaeris radicata*	1, 2, 5, 6, 7, 8, 9, 10
**Lactuca serriola*	1, 5
Lagenifera stipitata	1, 5, 7
Leucochrysum albicans var. *albicans*	10
Microseris lanceolata	5, 6
Olearia elliptica	1, 2, 3, 4, 5, 6, 7, 8, 10
Olearia erubescens	2
Olearia ramosissima	2
Olearia rosmarinifolia	2, 6
Olearia viscidula	1, 2, 3, 4, 5, 6, 7, 8
Ozothamnus obcordatus	3, 9, 10
Podolepis jaceoides	1, 7
Podolepis neglecta	10
Rhodanthe anthemoides	5
Rhodanthe diffusa subsp. *leucactina*	0

Senecio diaschides	1, 2, 4, 5, 6, 7
Senecio hispidulus var. *dissectus*	2, 6, 8
Senecio hispidulus var. *hispidulus*	6
Senecio lautus subsp. *dissectifolius*	2, 6, 10
Senecio sp. *E*	5
Sigesbeckia australiensis	1, 2, 6, 7
**Sigesbeckia orientalis* subsp. *orientalis*	0
**Sonchus oleraceus*	5, 7
**Taraxacum officionale*	5
Triptilodiscus pygmaeus	10
Vernonia cinerea	2, 7, 8
Vittadinia cervicularis var. *cervicularis*	4, 8
Vittadinia cuneata var. *cuneata*	
f. *minor*	1, 2, 5, 6, 7
var. *hirsuta*	10
Vittadinia muelleri	0
Vittadinia sulcata	0
Bignoniaceae	
Pandorea pandorana	0
Brassicaceae	
Lepidium pseudohyssopifolium	7
Cactaceae	
**Opuntia aurantiaca*	0
**Opuntia stricta*	2, 4, 7, 10
Campanulaceae	
Wahlenbergia communis	1, 2, 3, 4, 5, 6, 7, 10
Wahlenbergia gracilis	1, 2, 5, 6, 9
Wahlenbergia graniticola	1, 6
Wahlenbergia luteola	1
Wahlenbergia planiflora subsp. *longipila*	1, 2, 4, 5, 6, 7, 10
Caryophyllaceae	
**Anagallis arvensis*	5, 7, 8
**Arenaria leptocladus*	2
**Cerastium glomeratum*	5
**Cerastium vulgare*	0
**Paronychia brasiliana*	2, 5
**Petrorhagia nanteuilii*	1, 5
Scleranthus biflorus	1, 2, 3, 4, 5, 6, 7
Stellaria angustifolia	5, 6, 7, 8, 11
Stellaria flaccida	5
**Stellaria media*	7, 8
Stellaria pungens	6, 7
Casuarinaceae	
Casuarina cunninghamiana	8
Celastraceae	
Cassine australis var. *angustifolia*	0
Maytenus silvestris	1, 4, 6, 7, 8
Chenopodiaceae	
Chenopodium pumilio	8
Einadia hastata	4
Einadia polygonoides	7, 8
Einadia trigonos subsp. *stellulata*	8
Clusiaceae	
Hypericum gramineum	1, 2, 5, 6, 7, 9, 10
Hypericum japonicum	1, 2, 5
Convulvulaceae	
Dichondra repens	1, 2, 4, 5, 6, 7, 8
Dichondra sp. *A*	1, 3, 4, 6, 7, 8
Crassulaceae	
Crassula helmsii	5
Crassula sieberiana	1, 2,3, 5, 6, 9, 10
Dilleniaceae	
Hibbertia acicularis	3, 4
Hibbertia cistoidea	9
Hibbertia linearis	2, 9
Hibbertia obtusifolia	1, 2, 3, 4, 5, 6, 7, 8, 10
Hibbertia riparia	1, 2, 3, 9, 10
Hibbertia sp. *nov.*	3, 9

Droseraceae	
Drosera burmannii	2, 9, 10
Drosera peltata	5, 6, 10
Drosera spatulata	0
Epacridaceae	
Brachyloma daphnoides subsp. *glabrum*	1, 2, 3, 4, 6, 7, 9, 10
Leucopogon lanceolatus var. *lanceolatus*	1, 2, 6, 9
Leucopogon melaleucoides	4
Leucopogon muticus	1, 2, 3, 4, 5, 6, 7, 9, 10
Leucopogon neo-anglicus	9
Leucopogon virgatus	1, 3
Lissanthe strigosa subsp. *subulata*	1, 2, 3, 5, 6, 7
Melichrus urceolatus	1, 2, 3, 4, 5, 6, 7, 10
Monotoca scoparia	1, 2, 3, 4, 5, 6, 7
Euphorbiaceae	
Phyllanthus gunnii	0
Phyllanthus subcrenulatus	7
Phyllanthus virgatus	1, 7
Poranthera microphylla	1, 2, 5, 6, 7
Fabaceae	
Acacia buxifolia subsp. *buxifolia*	2, 3, 6
Acacia cheelii	4, 9
Acacia implexa	3, 4, 7, 8
Acacia leucocalyx	1, 2, 5
Acacia montana	0
Acacia neriifolia	1, 2, 3, 4, 5, 6, 7, 9, 10
Acacia obtusifolia	2
Acacia penninervis	1, 2, 3, 4, 6, 7, 10
Acacia pruinosa	1, 3, 7
Acacia rubida	5
Acacia triptera	6, 7, 9, 10
Acacia ulicifolia	1, 2
Acacia venulosa	0
Acacia viscidula	3, 5, 9
Aotus subglauca var. *filiformis*	0
Bossiaea obcordata	0
Bossiaea prostrata	1, 2
Daviesia latifolia	2
Desmodium brachypodum	1,4, 6, 7, 10
Desmodium varians	1, 2, 4, 5, 6, 7, 8, 10
Dillwynia retorta	0
Dillwynia sieberi	5
Glycine clandestina	1, 2, 4, 6, 7, 8
Glycine stenophita	7
Glycine tabacina	1, 2, 3, 4, 6, 7, 10
Hardenbergia violacea	1, 2, 3, 4, 5, 6, 7
Hovea apiculata	2, 9
Hovea graniticola	3, 10
Hovea heterophylla	1, 2, 3, 5
Hovea lanceolata	10
Indigofera adesmiifolia	1, 2, 4, 5, 6
Indigofera australis	1, 2, 3, 7
Jacksonia scoparia	0
Lespedeza juncea subsp. *sericea*	1, 7, 8
Lotus australis	1, 5
Lotus cruentus	1, 2, 5
**Lotus uliginosus*	5, 11
**Medicago polymorpha*	0
Mirbelia pungens	9, 10
Mirbelia speciosa subsp. *speciosa*	0
Pultenaea campbellii [*P. setulosa*]	2, 6
Pultenaea spinosa	0
Pultenaea foliolosa	1, 2, 3
Pultenaea sp. *C*	1, 3, 4, 6, 7
Pultenaea sp. *G*	1, 2, 4, 5, 6, 10
Swainsona galegifolia	7
**Trifolium repens*	1, 5, 6, 11
**Vicia villosa.*	5
Zornia dyctiocarpa var. *dyctiocarpa*	5, 7

Gentianaceae	
Centaurium erythraea	1, 2, 5, 7
Geraniaceae	
Geranium solanderi var. *grande*	11
Geranium solanderi var. *solanderi*	1, 2, 4, 5, 6, 7, 8, 10, 11
Pelargonium australe	
Goodeniaceae	
Goodenia bellidifolia subsp. *argentea*	1
Goodenia glabra	0
Goodenia hederacea subsp. *hederacea*	1, 2, 3, 4, 5, 6, 10
Goodenia macbarronii	1, 2, 3, 5, 10
Goodenia rotundifolia	2
Haloragaceae	
Gonocarpus micranthus subsp. *micranthus*	5, 11
Gonocarpus teucrioides	9
Gonocarpus tetragynus	1, 2, 3, 5, 6, 7, 9, 10
Haloragis heterophylla	1, 5, 6, 7, 10
Haloragis serra	6, 7
Myriophyllum crispatum	5, 8
Myriophyllum pedunculatum	0
Lamiaceae	
Ajuga australis	1, 2, 3, 4, 6, 7, 10
Mentha satureioides	5, 6, 7
Plectranthus graveolens	4
Plectranthus parviflorus	0
Prostanthera graniticola	9
Prostanthera nivea var. *nivea*	5, 9
Scutellaria humilis	1, 2, 4, 5, 6, 7, 8
Westringia eremicola	1, 2, 5, 6
Lauraceae	
Cassytha pubescens	2, 6, 9
Lentibulariaceae	
Utricularia dichotoma	0
Lobeliaceae	
Isotoma anethifolia	9, 10
Isotoma fluviatilis subsp. *borealis*	5, 8
Lobelia gracilis	9, 10
Pratia purpurascens	0
Loranthaceae	
Amyema miquelii	1, 4, 5, 7
Amyema miraculosum subsp. *boormanii*	9
Amyema pendula	0
Dendrophthoe glabrescens	0
Lythraceae	
Lythrum salicaria	0
Malvaceae	
**Modiola caroliniana*	8
Sida cunninghamii	7
Menyanthaceae	
Nymphoides geminata	0
Moraceae	
**Ficus carica*	0
Ficus rubiginosa	2, 4, 6
Myrtaceae	
Angophora floribunda	1, 2, 3, 4, 5, 6, 7, 8
Callistemon pungens	5, 6, 7, 8, 11
Calytrix tetragona	2, 3, 5, 6, 9, 10
Eucalyptus albens	4, 7
Eucalyptus andrewsii	1, 2, 3, 4, 5, 6, 7
Eucalyptus blakelyi	1, 5, 6, 7, 8, 10
Eucalyptus bridgesiana	1, 2, 5, 6, 7, 8
Eucalyptus caleyi subsp. *caleyi*	1, 2, 3, 4, 5, 6, 7, 10
Eucalyptus dealbata	1, 2, 4, 7, 9, 10
Eucalyptus macrorhyncha	1, 2, 3, 4, 5, 6, 7, 8
Eucalyptus melliodora	1, 2, 3, 4, 6, 7
Eucalyptus prava	1, 2, 3, 4, 5, 6, 8, 9, 10

Eucalyptus quinniorum	1, 2, 3, 4, 5, 6
Eucalyptus subtilior	6
Homoranthus bornhardtiensis	9, 10
Kunzea obovata	0
Kunzea parvifolia	7, 9
Leptospermum brachyandrum	0
Leptospermum brevipes	6, 7, 9, 10
Leptospermum novae-angliae	9
Leptospermum polygalifolium	
subsp. *montanum*	11
subsp. *transmontanum*	1, 5, 6, 7
Leptospermum variabile	0
Micromyrtus sessilis	0
Oleaceae	
Jasminum sauvissimum	3
Notelaea microcarpa var. *microcarpa*	1, 3, 4, 5, 6, 7, 8, 10
var. *velutina*	8
Onagraceae	
Epilobium billardierianum	
subsp. *cinereum*	1, 5, 6, 7, 11
Oxalidaceae	
Oxalis chnoodes	1, 2, 4, 5, 6, 7
Oxalis perennans	1, 5, 8
Phytolaccaceae	
**Phytolacca octandra*	0
Pittosporaceae	
Billardiera scandens var. *scandens*	2, 6
Bursaria spinosa var. *obovata*	4, 6, 7
Pittosporum undulatum	4, 6
Rhytidosporum procumbens	1, 3
Plantaginaceae	
Plantago debilis	1, 6
**Plantago lanceolata*	5
Plantago varia	1, 2, 4, 5, 6, 7, 10
Polygalaceae	
Polygala japonica	1
Polygonaceae	
**Acetosella vulgaris*	5, 7
Persicaria decipiens	5
Persicaria hydropiper	7, 8
Persicaria praetissima	0
Rumex brownii	1, 5, 6, 7, 8
Portulacaceae	
Calandrinia eremaea	2, 3, 5, 9, 10
Portulaca bicolor	0
Proteaceae	
Grevillea floribunda	0
Grevillea triternata	1, 3, 4, 5, 7, 10
Hakea eriantha	0
Hakea microcarpa	11
Lomatia silaifolia	2, 6
Persoonia chamaepeuce	3
Persoonia cornifolia	1, 2, 3, 5, 6, 7
Persoonia fastigata	0
Persoonia sericea	1, 2, 3, 5, 6
Ranunculaceae	
Clematis aristata	0
Clematis glycinoides	1, 2, 3, 4, 5, 6, 7
Ranunculus lappaceus	1, 2, 5, 6
Ranunculus sessiliflorus var. *sessiliflorus*	6
Ranunculus sp. *A*	11
Rhamnaceae	
Cryptandra amara var. *floribunda*	4, 9, 10
Rosaceae	
Acaena novae-zelandiae	1, 2, 4, 5, 6, 7
**Rosa rubiginosa*	0
**Rubus chloocladus*	1, 5, 6, 7, 8
Rubus parvifolius	2, 5, 6

Rubiaceae	
Asperula conferta	1, 5, 6, 7
Galium binifolium	1, 5, 6
Galium gaudichaudii	1, 2, 6, 7
Galium migrans	1, 2, 5, 6, 7, 8, 10
Galium propinquum	1, 2, 6
Opercularia aspera	1, 4, 7
Opercularia diphylla	1, 2, 3, 7, 10
Opercularia hispida	2, 5
Pomax umbellata	1, 2, 3, 4, 5, 9, 10
Psydrax odoratum	0
Rutaceae	
Boronia anethifolia	9
Correa reflexa var. *reflexa*	1, 2, 3, 4, 5, 6
Zieria aspalathoides	0
Zieria cytisoides	5, 7
Zieria odorifera	3
Santalaceae	
Exocarpos cupressiformis	1, 2, 3, 6
Leptomeria drupacea	0
Sapindaceae	
Alectryon subdentatus	
forma *subdentatus*	0
Dodonaea boroniifolia	2
Dodonaea viscosa subsp. *spatulata*	1, 2, 3, 5, 7, 10
Scrophulariaceae	
Derwentia arenaria	2, 4, 5, 6, 7
Derwentia perfoliata	1, 2, 3, 5, 6
Gratiola peruviana	5, 6
**Verbascum thapsus*	7
Veronica calycina	1, 2, 3, 6
Solanaceae	
Cyphanthera albicans subsp. *albicans*	9
Solanum amblymerum	3
Solanum cinereum	0
Solanum elegans	2, 6
**Solanum nigrum*	6, 8
Stackhousiaceae	
Stackhousia monogyna	1, 2, 6, 7
Stackhousia viminea	1, 2
Sterculiaceae	
Brachychiton populneus	1, 4, 7, 8
Stylidiaceae	
Stylidium graminifolium	1,3, 7
Thymelaeaceae	
Pimelea linifolia subsp. *caesia*	3
Pimelea strigosa	4
Urticaceae	
Urtica incisa	7, 8
Verbenaceae	
**Verbena bonariensis*	1, 5
**Verbena rigida*	1
Viscaceae	
Notothixos subaureus	0
Violaceae	
Hybanthus monopetalus	1
Viola betonicifolia	1, 2, 3, 5, 6
Viola caleyana	5, 8
Viola hederacea	5, 8

The vegetation of Peery Lake area, Paroo-Darling National Park, western New South Wales

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Abstract: The vegetation of Peery Lake area, Paroo-Darling National Park (32°18'–32°40'S, 142°10'–142°25'E) in north western New South Wales was assessed using intensive quadrat sampling and mapped using extensive ground truthing and interpretation of aerial photograph and Landsat Thematic Mapper satellite images. 378 species of vascular plants were recorded from this survey from 66 families. Species recorded from previous studies but not noted in the present study have been added to give a total of 424 vascular plant species for the Park including 55 (13%) exotic species. Twenty vegetation communities were identified and mapped, the most widespread being *Acacia aneura* tall shrubland/tall open-shrubland, *Eremophila/Dodonaea/Acacia* open shrubland and *Maireana pyramidata* low open shrubland. One hundred and fifty years of pastoral use has impacted on many of these communities.

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Introduction

Peery Lake area of Paroo–Darling National Park (32°18'–32°40'S, 142°10'–142°25'E) is located in north western New South Wales (NSW) 110 km north east of Broken Hill (Figure 1). It covers an area of approximately 96 000 ha. Major features are Peery Lake, a part of the Paroo overflow, and the rugged sandstone hills to the west of the lake. The Park was created in September 2000 from three pastoral stations: Peery, Mandalay and Arrow Bar. An intensive vegetation survey was undertaken in October 2001.

History of the area

Prior to European settlement nomadic Aboriginal tribes who were able to travel away from permanent soaks, waterholes and native wells inhabited the area after favourable rains. The Paakantji Aboriginal people travelled the length of the Darling River from Wilcannia through Menindee towards Wentworth. The large number of middens and stone relics encountered today evidences their strong ties to the river (H. Johnston, NSW National Parks and Wildlife Service, Buronga, pers. comm.). The first Europeans to travel through the area were Sturt and his party who followed the Darling to Menindee and then travelled west to the Barrier Range and north into Queensland (Stanley 1991). Soon after, others followed the Darling River in search of pasture for sheep. Robert Gow explored the area in 1861 in search of suitable pastures (Jervis 1947) but Vincent Dowling, who had established a cattle station close to the mouth of the Warrego River, had explored the Paroo to the north-west in 1860 and applied for grazing rights (Heathcote 1965). The township of Wilcannia was surveyed in 1865 and soon thrived (Hardy 1969). Previously there was just a woolshed and a few huts at Mount Murchison Station. Soon after, 38 runs were taken up as *Momba*, which absorbed the existing Mount Murchison lease, with a total area of 848 000 ha (Pickard 1990). Smith, Elder and Waite held the *Momba* pastoral lease from early 1870 (Heathcote 1965). In 1889 it was reported that Momba was overrun by kangaroos (Heathcote 1965). About this time a party of shooters found opal in the sandstone hills and by the 1890s White Cliffs township was established (Hardy 1969). With the development of pastoral leases in the 1850s, Aboriginal people were moved from their traditional homes to government missions at Menindee, Ivanhoe and Lake Cargelligo.

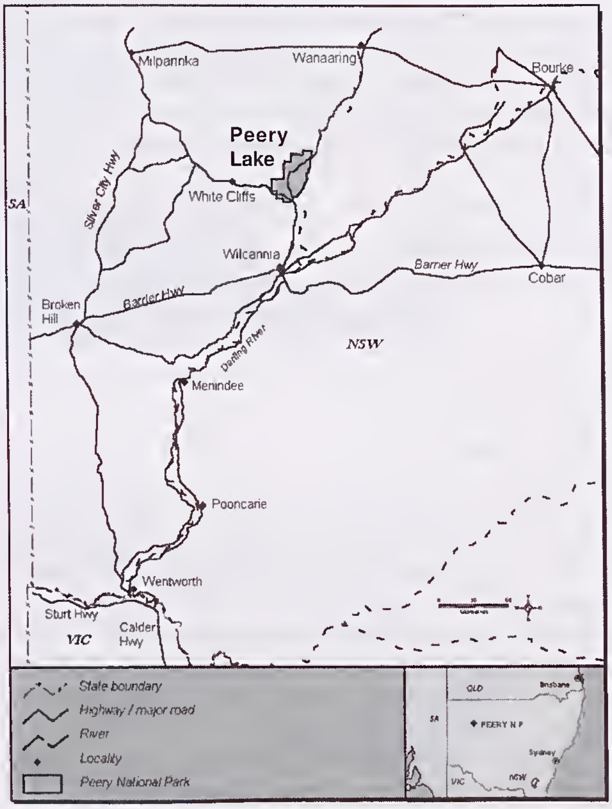


Fig. 1. Location of Peery Lake area, Paroo–Darling National Park

The combination of drought and overstocking made the normal recurrence of drought a major disaster. Whereas the land returned rapidly from 'desert' to 'vital glory' after the 1865–70 drought, this was no longer the case by the end of the century. By 1901 there was a catastrophic decline in productivity in the West Darling area. Sheep numbers went from less than 2 million prior to 1880 to a peak of nearly 8 million by 1894 but had declined to less than 3 million again by 1901. From 1902, *Momba* was successively subdivided until around 1950 when the residue was divided into ten leases which included Peery, Mandalay and Arrow Bar (Pickard 1990). Peery Lake part of Paroo-Darling National Park, based on Peery Station was established in 2000 to protect the cultural and biological features of land systems associated with the Paroo overflow. It was extended by the addition of Mandalay and Arrow Bar Stations in 2001.

Climate

The climate is described as arid with low and unreliable rainfall (Edwards 1979). Temperatures are high in summer and mild in winter with average daily maximum of 35°C in January and 17°C in July and average daily minimum of 21°C in January and 4°C in July. The mean annual rainfall is approximately 250 mm and annual potential evaporation is 2738 mm. There is a slight summer bias to rainfall and annual variation is high (Clewett et al. 1994). The survey was undertaken following heavy rain in September, four weeks previously and thus produced ideal conditions for survey.

Geology and geomorphology

Three physiographic regions (Abraham 1991) occur within the Park. The Paroo plains of the eastern sector are separated from the Stony Tablelands and Plains by the Mount Pleasant sandstone hills (Morton 1991). The twelve land systems present (Milthorpe et al. 1991) are summarised in Table 1.

Previous studies

The most complete study of the vegetation of Far Western New South Wales is that by Beadle (1945, 1948) who included the study area as *Acacia aneura* association with claypans and swamps associated with the channels of the Paroo. The area is included in the erosion survey of the Paroo–Upper Darling (James 1960) who mapped the vegetation of the Paroo–Upper Darling Region including the Peery Lake area: Mulga in the west, Belah–Acacia in the north east and claypan and canegrass in the south east. Milthorpe (1991) gave an account of the vegetation of the north west corner of NSW, which included Peery Lake. Pickard (1993) gave an account of the vegetation of the area occupied by the original Momba Station which also included land now in the Park and Pickard & Norris (1994) produced a map of the natural vegetation of north-western NSW at 1:1 000 000 scale. The mound springs on Peery Lake were included in a report on artesian springs in the Western Division of NSW (Pickard 1992). Parts of the area now included in Peery Lake Paroo–Darling National Park were included in studies undertaken for the Wilderness Society (Lembit 1992, Knight 1994). The former study was conducted during drought conditions with limited ground cover present (Lembit 1992). A detailed survey and vegetation map for Kinchega National Park to the southwest (Westbrooke et al. 2001) has also been published. No systematic survey of the vegetation of Peery Lake area has been undertaken prior to this study.

Table 1. Land systems present in the area (Milthorpe et al. 1991)

Relief	Land system	Characteristics & occurrence
Playas & basins	Cobham	Saltlakes with fringing dunes around Peery Lake
Sandplains & dunefields	Gumbalara	Sandplains with claypans & scattered swamps in lower reaches of Pine & Mirriappa Creeks
Sandplains & dunefields	Klondyke	Dunefields with calcareous swales east of Peery Lake
Alluvial plains	Yapunyah	Broad floodplains of creeks flowing into Peery Lake
Alluvial plains	Fowlers	Frontages of Pine & Mirriapa Creeks
Rolling downs & lowlands	Euramurtie	Sandy areas associated on the footslopes of the sandstone hills west of Peery Lake
Rolling downs & lowlands	Katalpa	Stony plains on the footslopes of hills. Upper reaches of Pine and Mirriappa Creeks
Rolling downs & lowlands	Glenhope	Stony plains, largely obscured by sand around Pine & Mirriappa Creeks
Rolling downs & lowlands	Oakvale	Stony plains between Wannara & Mirriapa Creeks
Hills & footslopes	Pulchra	Stony plains with low rock rises northwest of Peery Lake
Tablelands	Questa Park	Stony plateaux in north of Peery Lake
Ranges	Mount Pleasant	Rounded sandstone hills west of Peery Lake

Methods

Following preliminary survey, 125 × 0.09 ha (30 m × 30 m) quadrats were sampled (Figure 2). All vascular plant species occurring in each quadrat were recorded, as was a cover abundance value, modified from Braun-Blanquet (1928) for each species. Quadrats were subjectively located following the method of Gullan (1978). This ensured that all communities were sampled and provided data on floristic variability within them. Communities were generally sampled in proportion to the area they covered but to enable characterisation of communities, those of limited distribution may have been relatively over-sampled. Sampling was undertaken in October and November 2001 following good spring rains, which resulted in good growth of the ground layer. Data from the quadrats were entered into a database and analysed using PATN (Belbin 1993) to determine the communities present. A species list was compiled incorporating all vascular plant species recorded from quadrats and additional species recorded opportunistically. Further restricted and/or interesting communities recorded

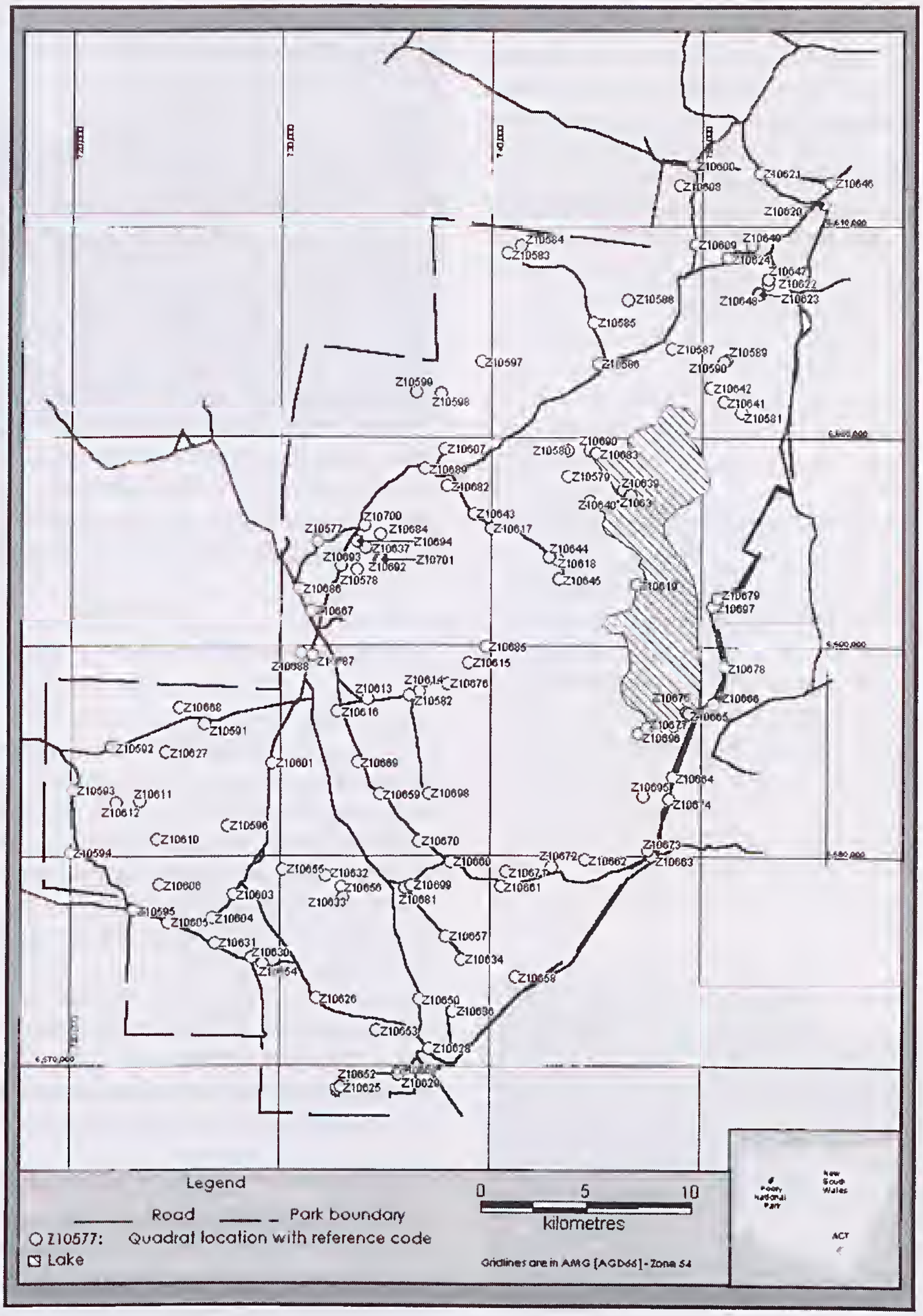

Legend
Road
Park boundary
○ Z10577: Quadrat location with reference code
Lake
0
5
10
kilometres
Gridlines are in AMG [AGD66] - Zone 54
Peery National Park
New South Wales
ACT

Fig. 2. Peery Lake area, quadrat locations

during the field work but not evident from the numeric classification were added to the final classification to provide twenty vegetation communities. For each community, mean species richness, total species richness and mean numbers of exotic species per quadrat were calculated (Table 2).

During surveys, ground truthing was undertaken by driven and walked transects. Information from these was used in conjunction with study of colour aerial photographs (Central Mapping Authority 1995) and Landsat Thematic Mapper satellite imagery (Scene 95–81) to produce a vegetation map at 1:100 000 scale. The mapped vegetation communities were defined by floristic and structural characteristics (Specht 1970). Sixteen communities identified from the vegetation classification were mapped at this scale. Because of the close association of *Eragrostis australasica* hummock grassland and *Muehlenbeckia florulenta* open shrubland and the difficulty of separation, these two communities have been combined on the map. Additional vegetation types of restricted occurrence e.g. *Hakea tephrosperma* tall open shrubland and

Halosarcia low open shrubland were located as points on the map. The classified image as transferred to the MapInfo Geographic Information System (MapInfo Corporation, Troy, New York) for final production of the vegetation map (Figure 3).

Table 2. Area, sampling intensity, species richness and weediness of plant communities of Peery National Park.

M: Mean species richness; **T:** Total species richness
Ex.: Mean exotic species; **Q:** Number of quadrats

Community	Approx area (%)	M	T	Ex.	Q
Eucalyptus camaldulensis open woodland (lake)	<1	35	41	3	4
Eucalyptus camaldulensis open woodland (creek)	2.5	27	155	8	7
Eucalyptus largiflorens open woodland	1.2	25	131	3	10
Eucalyptus ochrophloia open woodland	<1	30	33	16	1
Eucalyptus intertexta open woodland	2.8	35	72	3	3
Eucalyptus populnea open woodland	<1	26	129	7	8
Casuarina pauper/ *Alectryon oleifolius* low open woodland	2.4	23	106	1	11
Flindersia maculosa low open woodland	2.9	19	41	1	4
Acacia aneura/ *Acacia tetragonophylla* tall open shrubland	4.6	33	116	2	9
Acacia aneura tall shrubland	33	26	132	1	14
Hakea tephrosperma tall open shrubland	<1	31	55	2	2
Muehlenbeckia florulenta open shrubland	2	16	18	2	2
Eremophila/*Dodonaea*/ *Acacia* open shrubland	14.2	29	167	2	17
Atriplex nummularia open shrubland	<1	15	18	3	1
Maireana pyramidata low open shrubland	13	22	78	2	6
Halosarcia low open shrubland	<1	17	17	1	1
Eragrostis australasica hummock grassland	1	15	53	1	5
Lakebed herbland	6.2	11	33	1	6
Mixed herbland	10.7	18	98	1	5
Mound springs community	<1	9	9	0	1*
Highly Disturbed sites	<1	35	140	11	7

* data from Pickard (1992).

Results

Vegetation

The vegetation of the study area consists predominantly of woodlands variously dominated by *Acacia aneura*, *Flindersia maculata*, *Casuarina pauper*, *Atalaya hemiglauca* and *Grevillea striata*. Many of these are degraded as a result of past clearing for pasture improvement. In the south west, around the channels of Wannara and Mirriapa Creeks are extensive mixed herblands dominated variously by *Sclerolaena* and *Atriplex* species or grasses, depending on the season. Along creeklines and around Peery and Poloko lakes gallery woodlands variously dominated by *Eucalyptus camaldulensis*, *Eucalyptus largiflorens*, *Eucalyptus populnea* subsp. *bimbil*, *Eucalyptus ochrophloia* and *Acacia stenophylla* occur. Twenty communities were recognised (Table 2). While several of these are of limited distribution they add significantly to the conservation values of the area. The approximate area occupied by each community, the sampling intensity, mean species richness, total species richness and mean weediness of these communities are given (Table 2). All vegetation communities identified are described below, grouped according to structural attributes. The distribution of vegetation types is shown on the vegetation map (Figure 3).

Woodlands

1. *Eucalyptus camaldulensis* open-woodland (lake fringe)

Eucalyptus camaldulensis open woodland (10 m tall) occurs in a generally narrow band around sections of the Paroo overflow Lakes Peery and Poloko. Common associated trees and tall shrubs include *Eucalyptus largiflorens*, *Acacia stenophylla* and *Myoporum montanum*. Understorey shrubs and tussock species frequently associated include *Atriplex* species, *Einadia nutans*, *Chenopodium curvispicatum*, *Enchylaena tomentosa*, *Muehlenbeckia florulenta* and *Cyperus gymnocaulos*. The ground layer is dominated by the natives *Heliotropium curassavicum*, *Halosarcia pergranulata*, *Daucus glochidiatus*, *Malacocera tricornis*, *Nicotiana velutina*, *Osteocarpum acropterum*, *Pterocaulon sphacelatum*, *Salsola kali* var. *kali*, *Sclerolaena intricata*, *Senecio lautus* subsp. *dissectifolius*, *Stemodia florulenta*, *Sporobolus mitchellii* and the exotic herbs *Sisymbrium erysimoides* and *Spergularia rubra*.

2. *Eucalyptus camaldulensis* open-woodland (creek bed)

A narrow band of *Eucalyptus camaldulensis* open woodland (10 metres tall) also occurs along larger creeks. Common associated trees and tall shrubs include *E. largiflorens*, *Acacia aneura*, *A. stenophylla*, *A. victoriae*, and *Myoporum montanum*. Understorey shrubs and tussock species frequently associated include *Eremophila longifolia*, *Senna artemisioides* noth. *artemisioides*, *Einadia nutans*, *Chenopodium curvispicatum*, *Enchylaena tomentosa* and the exotic *Lycium ferrocissimum*. The ground layer is dominated by the natives *Daucus glochidiatus*, *Nicotiana velutina*, *Pterocaulon sphacelatum*, *Ptilotus atriplicifolius* subsp. *atriplicifolius*, *Rhodanthe floribunda*, *Rutidosis floribunda*, *Salsola kali* var. *kali*, *Malvastrum americanum*, *Mentha australis*, *Senecio cunninghamii*, *Tetragonia eremaea*, *Themeda australis*, *Vittadinia triloba*, *Wahlenbergia stricta*, *Brachyscome ciliaris*, *Bracteantha bracteata*, *Calotis pumulifera*, *Abutilon leucocephalum*, *Aristida ramosa* var. *ramosa*, *Eragrostis dielsii*, *Euphorbia drummondii*, *Gnephosis arachnoidea*,

A narrow band of *Eucalyptus camaldulensis* woodland occurs along major creeks.

Solanum esuriale, S. ellipticum, Oxalis corniculata, and the exotic herbs *Sisymbrium erysimoides, Solanum nigrum, Sonchus oleraceus, Centaurea melitensis, Anagallis arvensis, Salvia verbenaca, Schismus barbatus, Malva parviflora, Medicago polymorpha, Echium plantagineum* and *Lactuca serriola.*

3. *Eucalyptus largiflorens* open-woodland

This open woodland (10 m tall) occurs on heavy soils around Peery and Poloko Lakes, an unnamed lake near the southern boundary, and along some creeklines. The tall shrub *Acacia stenophylla* is frequently associated. Understorey shrubs and tussock species frequently associated include *Einadia nutans, Enchylaena tomentosa, Muehlenbeckia florulenta* and *Cyperus gymnocaulos.* Common components of the ground layer include the natives *Atriplex* species, *Heliotropium curassavicum, Malacocera tricornis, Nicotiana velutina, Osteocarpum acropterum, Myriocephalus stuartii, Gnephosis arachnoidea, Pterocaulon sphacelatum, Salsola kali* var. *kali, Rutidosis helichrysoides, Sclerolaena intricata, Senecio lautus* subsp. *dissectifolius, Senecio runcinifolius, Sporobolus mitchellii, Teucrium racemosum,* and the exotic herbs *Solanum nigrum* and *Centaurea melitensis.*

4. *Eucalyptus ochrophloia* open-woodland

Open-woodland dominated by *Eucalyptus ochrophloia* with *Eucalyptus largiflorens* associated occurs along the channels of the Paroo overflow, south of Peery Lake. Except where *Muehlenbeckia florulenta* occurs in lower sites the shrub layer is restricted to low chenopods such as *Einadia nutans* and *Sclerolaena* species. The ground layer includes *Atriplex leptocarpa, Acacia lindleyi, Chamaesyce drummondii, Malacocera tricornis, Osteocarpum acropterum, Halosarcia pergranulata, Salsola kali* var. *kali, Tetragonia eremaea* and the exotics *Centaurea melitensis* and *Schismus barbatus.*

5. *Eucalyptus intertexta* open-woodland

This open woodland (10 m tall) occurs on the sandy lower slopes of the rocky hills west of Peery Lake. The tall shrubs *Acacia aneura, Alectryon oleifolius* and *Eremophila longifolia* are frequently associated. Understorey shrubs and tussock species frequently associated include *Chenopodium curvispicatum, C. desertorum, Einadia nutans, Enchylaena tomentosa, Eremophila sturtii, Maireana triptera, Sclerolaena diacantha* and *Senna artemisioides* noth. *artemisioides.* The ground layer is dominated by the natives *Eragrostis dielsii, Boerhavia dominii, Brachyscome lineariloba, Chenopodium cristatum, Convolvulus erubescens, Cynoglossum australe, Solanum ellipticum, Stenopetalum lineare* and *Tetragonia eremaea* and the exotics *Schismus barbatus* and *Sisymbrium erysimoides.*

6. *Eucalyptus populnea* open-woodland

This open woodland (10 m tall) dominated by *Eucalyptus populnea* subsp. *bimbil* is associated with drainage lines and creeks. Understorey shrubs and tussock species frequently associated include *Acacia victoriae, Chenopodium curvispicatum, Maireana brevifolia, Rhagodia spinescens* and *Myoporum montanum.* The ground layer is dominated by the natives *Atriplex stipitata, Bracteantha bracteata, Calotis* species, *Eragrostis laniflora, Oxalis corniculata, Harmsiodoxa blennodioides, Rhodanthe floribunda, Rutidosis helichrysoides, Tetragonia eremaea* and *Wahlenbergia stricta* and the exotics *Centaurea melitensis, Anagallis arvensis, Schismus barbatus, Sisymbrium erysimoides* and *Sonchus oleraceus.*

Eucalyptus populnea open woodland occurs along creeks and shallow drainage lines.

7. *Casuarina pauper/Alectryon oleifolius* woodland/open-woodland

Casuarina pauper woodland/open-woodland growing to 10–12 metres tall is widespread on undulating sandplains. Most commonly associated understorey shrubs are *Enchylaena tomentosa, Maireana pyramidata, M. triptera, Rhagodia spinescens, Chenopodium curvispicatum* and *Myoporum montanum.* Common ground layer species include *Rhodanthe floribunda, Tetragonia eremaea, Salsola kali* var. *kali, Gnephosis arachnoidea, Enteropogon acicularis,* *Atriplex holocarpa*, *A. stipitata*, *Sclerolaena intricata*, *S. obliquicuspis*, *Senecio lautus* subsp. *dissectifolius* and *Brachyscome ciliaris* var. *lanuginosa*.

Casuarina pauper/*Alectryon oleifolius* low open woodland is widespread on undulating sandplains.

8. *Flindersia maculosa* low open-woodland

Low open woodland dominated by *Flindersia maculosa* occurs on scattered localities on low hills and sandplains. *Acacia aneura* and *Alectryon oleifolius* are frequently associated. Associated shrubs include *Enchylaena tomentosa*, *Eremophila duttonii*, *Eremophila sturtii*, *Chenopodium desertorum*, *Maireana pyramidata*, *M. triptera*, and *Atriplex stipitata*. Commonly associated herbs and sub-shrubs include *Sclerolaena intricata*, *Einadia nutans*, *Rhodanthe floribunda*, *Stenopetalum lineare*, *Gnephosis arachnoidea*, *Salsola kali* var. *kali*, *Tetragonia eremaea*, *Goodenia pinnatifida* and *Calotis plumulifera*.

Shrublands/tall shrublands

9. *Acacia aneura*/*A. tetragonophylla* tall open-shrubland

Tall open shrubland dominated by *Acacia aneura*, frequently associated with *Grevillea striata* occurs on the rocky hills to the west of Peery Lake. Associated shrubs include *Enchylaena tomentosa*, *Maireana triptera*, *Eremophila duttonii*, *Eremophila longifolia*, *Eremophila sturtii*, *Eremophila serrulata*, *Senna artemisioides* noth. *artemisioides*, *Prostanthera striatiflora*, *Indigofera australis*, *Acacia brachystachya and Acacia tetragonophylla*. A very diverse ground layer includes *Sclerolaena convexula*, *Convolvulus erubescens*, *Oxalis corniculata*, *Sida corrugata*, *Sida cunninghamii*, *Einadia nutans*, *Tetragonia eremaea*, *Calotis plumulifera*, *Calotis cuneifolia*, *Canthium odoratum*, *Solanum ellipticum*, *Euphorbia drummondii*, *Boerhavia dominii*, *Stenopetalum lineare*, *Brachyscome linearis*, *Wahlenbergia stricta*, *Daucus glochidiatus*, *Cheilanthes austrotenuifolia*, *Cheilanthes lasiophylla* and *Austrostipa scabra*.

Acacia aneura tall shrubland is the most extensive community, occurring on undulating sandplains and low hills.

10. *Acacia aneura* tall shrubland

Tall open shrubland dominated by *Acacia aneura*, frequently associated with *Flindersia maculosa* and *Grevillea striata* occurs on undulating sandplains and low hills. Associated shrubs include *Enchylaena tomentosa*, *Maireana triptera*, *Eremophila duttonii*, *E. longifolia*, *E. sturtii*, and *Acacia tetragonophylla*. Common low shrubs and herbs include *Sclerolaena bicornis* subsp. *bicornis*, *S. diacantha*, *S. intricata*, *Atriplex limbata*, *A. stipitata*, *Convolvulus erubescens*, *Oxalis corniculata*, *Rhodanthe floribunda*, *Rutidosis helichrysoides*, *Stenopetalum lineare*, *Gnephosis arachnoidea*, *Harmsiodoxa blennodioides*, *Sida corrugata*, *Einadia nutans*, *Salsola kali* var. *kali*, *Chenopodium cristatum* and *Tetragonia eremaea*. Exotic species occurring in this community include *Centaurea melitensis*, *Sisymbrium erysimoides* and *Sonchus oleraceus*.

11. *Hakea tephrosperma* tall open-shrubland

Small patches of tall open-shrubland dominated by *Hakea tephrosperma* occur to the south of Mandalay sheering shed. Tall shrub associates included *Acacia aneura*, *Dodonaea viscosa* subsp. *angustissima* and *Eremophila sturtii*. Low shrubs and herbs in the ground layer include *Solanum ellipticum*, *Tetragonia eremaea*, *Rhodanthe floribunda*, *Gnephosis arachnoidea*, *Austrostipa scabra* and *Maireana triptera*.

Small areas of *Hakea tephrosperma* tall open shrubland occur south and east of the old Mandalay shearing shed.

Low open-shrublands

12. *Muehlenbeckia florulenta* open-shrubland

Low open shrubland dominated by *Muehlenbeckia florulenta* occurs in low-lying areas around Peery and Poloko Lakes. *Eragrostis australasica* is frequently associated and the community may grade into one dominated by that species. Frequently associated low shrubs and herbs include *Sclerolaena divaricata, Sclerolaena stelligera, Sclerolaena intricata, Chamaesyce drummondii, Osteocarpum acropterum, Rutidosis helichrysoides, Tetragonia eremaea, Epaltes cunninghamii* and *Brachyscome lineariloba.*

13. *Dodonaea viscosa* subsp. *angustissima/Senna artemisioides/ Eremophila* species shrubland

Associated with *Casuarina pauper/Alectryon oleifolius* woodland/open-woodland and *Acacia aneura* low open woodland are areas of mixed species shrubland in which *Dodonaea viscosa* subsp. *angustissima, Acacia victoriae, Senna artemisioides* subsp. *filiformis* and *Eremophila sturtii* are prominent. *Acacia aneura* may provide a sparse overstorey. Other associated shrubs include *Enchylaena tomentosa, Maireana pentatropis* and *Chenopodium curvispicatum.* Common low shrubs and herbs include *Sclerolaena bicornis* subsp. *bicornis, Sclerolaena diacantha, Einadia nutans, Atriplex limbata, Atriplex stipitata, Daucus glochidiatus, Convolvulus erubescens, Oxalis corniculata, Rhodanthe floribunda, Rutidosis helichrysoides, Stenopetalum lineare, Solanum esuriale, Brachyscome lineariloba, Gnephosis arachnoidea, Harmsiodoxa blennodioides, Calotis plumulifera, Enneapogon avenaceus, Austrostipa scabra and Wahlenbergia stricta.*

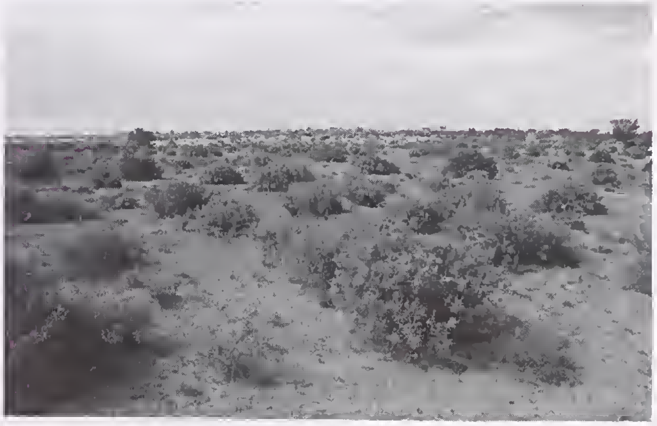
An *Eremophila/Dodonaea/Acacia* mixed shrubland may be the result of past disturbance of woodland communities.

14. *Atriplex nummularia* open-shrubland

An open shrub community dominated by *Atriplex nummularia* occurs to the east of Peery Lake. Associated species include *Maireana pyramidata, Sclerolaena intricata, Sida intricata, Daucus glochidiatus, Myriocephalus stuartii, Rhodanthe moschata, Salsola kali* var. *kali, Tetragonia eremaea* and the exotics *Brassica tournefortii* and *Cucumis myriocarpus.*

15. *Maireana pyramidata* low open-shrubland

A low open shrubland dominated by *Maireana pyramidata* occurs on broad drainage lines and on lower slopes of rises, largely in the north east of the Park. Commonly associated low shrubs and herbs include *Atriplex stipitata, Stenopetalum lineare, Tetragonia eremaea, Rhodanthe floribunda, Gnephosis arachnoidea, Daucus glochidiatus, Einadia nutans, Chamaesyce drummondii, Sclerolaena intricata, Enneapogon avenaceus* and *Sida intricata* along with the exotic *Schismus barbatus.*



Maireana pyramidata low open shrubland is widespread in the north of the park on broad drainage lines and lower slopes.

16. *Halosarcia* low open-shrubland

A low open shrubland dominated by *Halosarcia pergranulata* subsp. *pergranulata* occurs in low-lying sites adjacent to Peery and Poloko Lakes and an unnamed lake near the southern boundary. Associated species include *Teucrium racemosum, Senecio lautus* subsp. *dissectifolius, Sclerolaena divaricata, Plantago drummondii, Gnephosis arachnoidea, Osteocarpum acropterum, Eragrostis dielsii, Centipeda cunninghamii, Atriplex holocarpa and Atriplex lindleyi.*

Grasslands/Herblands

17. *Eragrostis australasica* grassland

Areas of *Eragrostis australasica* grassland occur around Peery and Poloko Lakes. *Muehlenbeckia florulenta* may be associated and the community may grade into a shrubland dominated by that species. Frequently associated low shrubs and herbs include *Sclerolaena intricata, Epaltes cunninghamii, Brachyscome lineariloba, Gnephosis arachnoidea, Atriplex holocarpa/Eragrostis setifolia, Pycnosorus globosus* and *Halosarcia pergranulata* subsp. *pergranulata.*

Eragrostis australasica grassland often associated with *Muehlenbeckia florulenta* shrubland occurs on low-lying areas around Peery Lake.

18. Lakebed herbland

As the lakes dry out after flooding an annual herbland develops. This is dominated by *Atriplex holocarpa, Sporobolus mitchellii, Spergularia rubra, Teucrium racemosum, Senecio lautus* subsp. *dissectifolius, Osteocarpum acropterum, Heliotropium curassavicum* and *Halosarcia pergranulata* subsp. *pergranulata.* Towards the lake edge scattered shrubs of *Muehlenbeckia florulenta* may occur.

19. Mixed herblands

A variety of herbland communities occur within the Park generally on low-lying areas, many of which may be subject to inundation particularly in the area to the east of Arrow Bar Homestead. Common dominants include *Atriplex lindleyi, A. holocarpa, Sclerolaena bicornis, Sclerolaena brachyptera, Sclerolaena intricata and Sclerolaena ventricosa.* Frequently associated small shrubs and herbs include *Maireana aphylla, Maireana coronata, Maireana turbinata, Swainsona campylantha, Swainsona affinis, Tetragonia eremaea, Plantago drummondii, Rhodanthe floribunda, Euphorbia drummondii, Eragrostis setifolia, Brachyscome ciliaris* and *Brachyscome lineariloba.* It is likely that the species composition of these areas is variable and dependant on seasonality of rainfall events, with grasses becoming more prominent following good summer rainfall. These herblands warrant a more detailed study through several seasons.

20. Mound Springs community

Active mound springs located along the eastern shore of Peery Lake carry a sedgeland community dominated by *Cyperus gymnocaulos* and *Cyperus laevigatus.* These springs have been documented by Pickard (1992). Of high significance is the presence of *Eriocaulon carsonii* and *Utricularia dichotoma.*

21. Disturbed sites

A number of quadrats were sampled at sites which had been subject to significant disturbance through the pastoral history of the properties, including homestead sites, earth tanks and yards. These had a high species richness and predictably, relatively high weediness.

Plant species

A total of 378 vascular plant species from 66 families were recorded during this study. A further 46 species have been recorded in previous surveys.

Occurrence of exotic species

Of the 424 species recorded from the Park, 55 (13%) were exotics. Mean percentage occurrence of exotic species ranged from 53% in the *E. ochrophloia* open woodland community to less than 1% in *Casuarina pauper/Alectryon oleifolius* low open woodland and *Acacia aneura* tall shrubland (Table 2). The highest levels of occurrence of exotic species were in communities subject to the greatest influence from water i.e. the open woodlands and herblands associated with the lakebeds and major creeks. This is in accord with Westbrooke (1990) who found a high negative correlation between occurrence of exotic species and distance from water in studies at Mallee Cliffs National Park and Nanya Station. A number of exotic species are winter rainfall stimulated and thus may not have been recorded during this survey. *Melia azedarach*, recorded as an artificial planting, although not naturalised, is of historic and cultural significance.

Discussion

Mapping communities

There are a number of inherent problems in vegetation mapping: vegetation mapping assumes discontinuities between communities which may not exist; the constraints of cartography determine the minimum area that can clearly be distinguished; it is generally not feasible to ground truth the whole of an area and thus parts of the map assume a consistent relationship between the vegetation and other features such as soil type and topography. Beadle's (1948) map of western NSW at approximately 1:1 000 000 scale includes two units for the area. James's (1960) map of the Paroo–Upper Darling shows three vegetation units and Milthorpe's 1:500 000 map of north western NSW shows five units. Pickard and Norris's (1994) map of north-western NSW shows nine vegetation units. In the attached map, sixteen units are mapped and a further four indicated by point location. The map nonetheless suffers from the limitations noted above. The smallest area that could be mapped was 100 m in width, but in the interest of clarity some vegetation types occurring in very narrow bands were exaggerated to this width. Similarly some areas remote from tracks may include small patches of another vegetation unit from that mapped. With the current technology of mapping enabling changes to be readily incorporated, it is hoped that the map will be refined with following botanical visits.

Distribution of communities

The distribution and species composition of vegetation communities within the Peery Lake area is largely determined by variation in topography, landform position and soil type. *Eucalyptus* species open woodlands are associated with texture contrast soils of the major creeklines and on clays around the overflow lakes. Shrubland dominated by *Acacia brachystachya* and *A. aneura* occurs on the lithosols of the sandstone hills with *Eucalyptus intertexta* woodland on the red earths that occur on the footslopes. Woodlands variously dominated by *Casuarina pauper, A. aneura* and *Flindersia maculosa* occur on desert loams and mixed herblands occur on the clays associated with the floodplains of Wannara Creek. *Maireana pyramidata* low open shrubland occurs on the east-west dunefields to the east of Peery Lake. Other factors, notably past grazing history, have also played a role in determining the present distribution and floristic composition of the communities present.

Conservation status of plant communities

The communities mapped do not directly correspond to those listed by Benson (1989) but nonetheless, based on his analysis, three communities, *Casuarina pauper/Alectryon oleifolius* woodland, *Muehlenbeckia florulenta* low shrubland and *Eragrostis australasica* hummock grassland should be regarded as vulnerable; the remaining communities are inadequately reserved.

The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin' is listed as endangered in Australia under the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act), and those occurring in New South Wales are also listed as endangered in the State under the *Threatened Species Conservation Act* 1995 (TSC Act). The listings include springs that are the natural surface discharge points of aquifers in the Triassic, Jurassic and Cretaceous sedimentary sequence of the Great Artesian Basin. The community comprises a variable range of native species that depend on the natural discharge of groundwater from the Great Artesian Basin for their existence. Those in north-western New South Wales often consist of sedges or similar vegetation as well as trees and shrubs which may occur near the springs. Major threats to this community are trampling and grazing by stock and feral animals, alteration of flow or unsustainable extraction of water from artesian bores reducing flows to the mound springs. The springs within Peery Lake are the only Artesian Springs reserved in NSW (NPWS 2001).

Plant species

Three hundred and seventy eight species of vascular plants were recorded during this study. Whilst this survey was undertaken in optimum conditions following good rains, a survey in one season only will not record all species present. Lembit (1993) in a survey during drought conditions recorded only 104 species. Of the 200 species previously recorded from the Park, 46 were not recorded during the present study. The total of 424 species reflects the diversity of environments and vegetation communities. Highest representation of species was from the Chenopodiaceae (65), Poaceae (60) and Asteraceae (52). Apart from communities associated with major disturbance, overall weediness of communities was low.

Rare, threatened or restricted species

Eucalyptus ochrophloia is restricted to a few watercourses and floodplains in southwest Queensland and north western NSW along the Paroo River (Brooker & Kleinig 1990). Three species are listed by Pressey et al. (1990) as having restricted distribution in western New South Wales. *Eriocaulon carsonii*, listed as endangered under the NSW *TSC Act*, occurs on a mound spring on the western edge of Peery Lake, this being the only known site for this species in NSW (Pickard 1992). *Utricularia dichotoma* previously described, also occurring on these mound springs, is now thought to be a new previously undescribed species (John Benson, Royal Botanic Gardens, pers. comm.). *Swainsona oligophylla* occurs in woodlands and herbfields on the edge of Peery Lake. *Cheilanthes lasiophylla* occurs in *Acacia aneura* tall open shrubland in sheltered situations on the rocky hills.

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Appendix 1. Plant species of Peery Lake area with frequency (%) of occurrence in communities

Vascular plant species recorded from Peery Lake area. Nomenclature is according to Harden (1990–1993).

*denotes exotic species ? denotes species recorded in that community but not quadrats.

# denotes species previously recorded for the Park but not during this study

Plant communities

1 *Eucalyptus camaldulensis* open woodland (lake)
2 *Eucalyptus camaldulensis* open woodland (creek)
3 *Eucalyptus largiflorens* open woodland
4 *Eucalyptus ochrophloia* open woodland
5 *Eucalyptus intertexta* open woodland
6 *Eucalyptus populnea* open woodland
7 *Casuarina pauper*/*Alectryon oleifolius* low open woodland
8 *Flindersia maculosa* low open woodland
9 *Acacia aneura*/*A. tetragonophylla* tall open shrubland
10 *Acacia aneura* tall shrubland
11 *Hakea tephrosperma* tall open shrubland
12 *Muehlenbeckia florulenta* open shrubland
13 *Eremophila*/*Dodonaea*/*Acacia* open shrubland
14 *Atriplex nummularia* open shrubland
15 *Maireana pyramidata* low open shrubland
16 *Halosarcia* low open shrubland
17 *Eragrostis australasica* hummock grassland
18 Lakebed herbland
19 Mixed herbland.
20 Mound springs community
21 Highly disturbed sites.

	Plant communities																				
Taxon family & name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Number of quadrats	4	7	10	1	3	8	11	4	9	14	2	2	17	1	6	6	5	4	5	1	8
FERNS																					
Adiantaceae																					
Cheilanthes austrotenuifolia					33				56	14											
Cheilanthes lasiophylla									44												
Marsileaceae																					
Marsilea drummondii		14				38							12		17	17	20		20		25
MONOCOTYLEDONS																					
Amaryllidaceae																					
Crinum flaccidum		14	10																		
Anthericaceae																					
Thysanotus baueri					33				22	7			12		17				20		
Asphodelaceae																					
Bulbine alata		14							22	7			18						20		
Cyperaceae																					
Cyperus alterniflorus		?	?	?																	
Cyperus gymnocaulos	100		40															25			13
Cyperus laevigatus	?																				100
#*Cyperus squarrosus*																					
Cyperus victoriensis	?	?	?																		
Eleocharis acuta																					13
Eleocharis pallens			?														?				
Eriocaulaceae																					
Eriocaulon carsonii																				100	
Juncaceae																					
Juncus aridicola																		?			
Phormiaceae																					
Dianella longifolia var. *longifolia*						13															
Poaceae																					
Agrostis avenacea var. *avenacea*																					
Aristida calycina var. *praealta*					33																
Aristida contorta										14			12		17						13
Aristida holathera var. *holathera*						13							6								
Aristida jerichoensis									11	7											
Aristida jerichoensis var. *jerichoensis*									11	7											
Aristida jerichoensis var. *subspinulifera*													6								
Aristida nitidula			10																		
Aristida ramosa		29				13															13
Astrebla lappacea							?	?		?											
Austrostipa nitida																					
Austrostipa scabra		14							11	7	50		6		17						25
# *Bothriochloa* sp.																					
Brachyachne ciliaris		29	20			25		25					18		33	67	20		60		25
**Bromus cartharticus*						13															
#*Bothriochloa* sp.																					
Chloris truncata							9			7			6				20				13
Cymbopogon ambiguus		14	10			13															

Taxon family & name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Number of quadrats	4	7	10	1	3	8	11	4	9	14	2	2	17	1	6	6	5	4	5	1	8
Cymbopogon obtectus		14								7			12								
# *Cynodon dactylon*																					
Dichanthium sericeum							9						6		17	17					
Digitaria brownii						?				?											
Digitaria coenicola										?											
Enneapogon avenaceus					?	?	?														
Enneapogon cylindricus										?							?				
Enneapogon polyphyllus						?				?											
Enteropogon acicularis							45		11	7											13
Enteropogon ramosus					?	?	?	?		?			?								
Eragrostis australasica			10			25						100					100	25			13
# *Eragrostis desertorum*																					
Eragrostis dielsii	25	29	10				9			7			12		50					100	25
Eragrostis eriopoda																17					
Eragrostis lacunaria									11												
Eragrostis laniflora					67					14											
Eragrostis leptocarpa	?	?										?									
Eragrostis setifolia												?			17	17					
Eriachne helmsii										?											
Eriachne mucronata									?												
# *Eriachne pulchella* subsp. *pulchella*																					
# *Eulalia aurea*																					
**Hordeum leporinum*																					13
Leptochloa digitata	?	?	?				?														
Monachather paradoxa					33				22	21	50										
# *Neurachne munroi*																					
Panicum simile													?								
Paspalidium constrictum																			?		
Paspalidium jubiflorum						13															
**Polypogon monspeliensis*																			?		
**Rostraria pumila*							9														
**Schismus barbatus*		43	10	100	100	25	18		11	14	50		24	100	67	17			20	100	50
Sporobolus actinocladus			?		?	?				?				?							
Sporobolus caroli							?							?							
Sporobolus mitchellii	50		40				9					50					40	100			
Themeda australis		43							56				12								
# *Themeda avenacea*																					
Thyridolepis mitchelliana						?				?											
Tragus australianus										7											
Tripogon loliiformis					?					?			?								
Triraphis mollis						?				?											
Typhaceae																					
**Typha domingensis*																		?			?
Xanthorrhoeaceae																					
Lomandra leucocephala subsp. *leucocephala*						?															
DICOTYLEDONS																					
Acanthaceae																					
Rostellularia adscendens subsp. *adscendens*		14	10			13															
Aizoaceae																					
# *Disphyma crassifolium* subsp. *clavellatum*																					
Gunniopsis septifraga	25																				
Tetragonia eremaea	25	57	60	100	67	88	100	100	44	64	100		76	100	83	83			40		75
Tetragonia tetragonoides		14				13				7											
Amaranthaceae																					
Alternanthera denticulata			10			13			22								20				
Alternanthera nodiflora			10																		
Ptilotus atriplicifolius var. *atriplicifolius*		29	10				18		56				6								
Ptilotus exaltatus var. *exaltatus*																					13
# *Ptilotus gaudichaudii* var. *gaudichaudii*																					
# *Ptilotus macrocephalus*																					
Ptilotus obovatus var. *obovatus*					33					14											13
Ptilotus polystachyus var. *polystachyus*					33	13				14			12								
Ptilotus spathulatus f. *spathulatus*					?	?	?	?	?												
Apiaceae																					
# *Cyclospermum leptophyllum*																					
Daucus glochidiatus		57	10		33	13	9		67		50		29	100	50	83			40	100	75
# *Eryngium plantagineum*																					

Taxon family & name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Number of quadrats	4	7	10	1	3	8	11	4	9	14	2	2	17	1	6	6	5	4	5	1	8
Hydrocotyle trachycarpa									11												
Trachymene ochracea	25				33				11	7											
Apocynaceae																					
# Parsonia eucalyptophylla																					
Asclepiadaceae																					
Marsdenia australis					33					7											
Rhyncharrhena linearis										7			6								
Asteraceae																					
#Agianthus burkittii																					
# Arctotheca calendula*																					
Brachyscome ciliaris var. *lanuginosa*	25	29	20		33	13	36			14			12		17				20		13
Brachyscome lineariloba	50	14	20	100	33	38	27		33	21		50	47		67	17	60	25	80		50
Bracteantha bracteata		29			67	13			44	50	50		12								
Calotis cuneifolia		14	10		67	25	9		78	29	50		6								
# Calotis erinacea																					
Calotis hispidula			10		67	13	27	25	22	21	50		12								25
Calotis plumulifera		29	20		67	25		50	33	57			53		50						38
**Carthamus lanatus*		14	10			13	9						12								
**Centaurea melitensis*	25	86	30	100	33	50	9		22	7	50		24		33			25			75
Centipeda cunninghamii			40			13							6					25		100	50
Centipeda thespidioides			10			13							6						20		
Chrysocephalum semicalvum subsp. *semicalvum*									11												
Epaltes australis			20																		13
Epaltes cunninghamii			10			13						100					40				
# Erioclamys behrii																					
Gnephosis arachnoidea	25	57	50	100	67	25	55	50	67	86	100	50	76		67	67	40		40	100	100
Gnephosis eriocarpa			10							7											
**Hedypnois rhagadioloides* subsp. *cretica*		29	10													17					13
Helichrysum semifertile			10																		
**Hypochaeris glabra*						13			22												
Isoetopsis graminifolia					?								?								
# Ixiolaena brevicompta																					
# Lactuca saligna*																					
**Lactuca serriola*	25	29				13															
# Millotia perpusilla																					
Minuria cunninghamii				100			9						18		33	17			20		
Myriocephalus stuartii	25	14	40			13			11				12	100	33		20				13
Podolepis capillaris			10																	100	
Pseudognaphalium luteoalbum			10						11												38
Pterocaulon sphacelatum	50	29	30			25				7			6								13
Pycnosorus chrysanthus			20										6				20				
Pycnosorus globosus		14	10														20	25			
Pycnosorus pleiocephalus			10								50		6								
Rhodanthe corymbiflora	25																				
Rhodanthe floribunda		71	40	100	100	63	55	50	67	71	100		88		100	67			80		75
Rhodanthe moschata		14	20		67				22				6	100							
Rhodanthe pygmaea			?	?	?	?															
Rutidosis helichrysoides		29	30		33	50			33	36		50	35		17		20	25			25
Senecio cunninghamii		29	10			13									17						
Senecio lautus subsp. *dissectifolius*	75	14	50	100		13	27			7			18	100	33	17	20	50		100	13
Senecio magnificus	25																				
Senecio quadridentatus						13	9											25			
Senecio runcinifolius			40																		25
**Silybum marianum*		14																			
**Sonchus oleraceus*		71	20			63	18	25	33	7			18		17	67					75
# Vittadinia cuneata																					
Vittadinia hispidula										7											
Vittadinia triloba		43	10						11	7											13
**Xanthium occidentale*																					25
**Xanthium spinosum*		14				13															
Boraginaceae																					
Cynoglossum australe		14			67																
**Echium plantagineum*		43	10		33	13			11				12								63
Heliotropium asperrimum			10																		
# Heliotropium brachygyne*																					
Heliotropium curassavicum	50		50															50			
Omphalolappula concava									11					100		17					
Plagiobothrys plurisepalus															17						
Trichodesma zeylanicum			10																		

Taxon family & name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Number of quadrats	4	7	10	1	3	8	11	4	9	14	2	2	17	1	6	6	5	4	5	1	8
Brassicaceae																					
**Alyssum linifolium*													6			17			20		
Arabidella eremigena			?			?				?											
Arabidella trisecta													12			17					
# Brassica rapae*																					
**Brassica tournefortii*						13							6	100							13
**Carrichtera annua*													12		17	17					25
Harmsiodoxa blennodioides					67	38			67	36	50		47		17				20		25
**Lepidium bonariense*		14																			
Lepidium oxytrichum									11												13
Lepidium papillosum						?								?							
Lepidium pseudohyssopifolium						?															
**Sisymbrium erysimoides*	50	100	20	100	67	100	9		11	21			29			33					88
**Sisymbrium irio*																	20				13
**Sisymbrium orientale*																					13
Stenopetalum lineare		14	10		67		27	50	33	43	50		65		33	17					13
Stenopetalum nutans										7											
Caesalpiniaceae																					
Petalostylis labicheoides var. *labicheoides*					?				?	?											
Senna artemisioides noth *artemisioides*		29			67	13			78	14			12			17					
Senna artemisioides noth *coriaceae*			10						11	7			12								
Senna artemisioides noth *sturtii*		14	10						11	14											
Senna artemisioides subsp. *filifolia*			10			13				14			41						20		13
Senna artemisioides subsp. *helmsii*										7											
Senna artemisioides subsp. *oligophylla*										14			6								
Senna artemisioides subsp. *petiolaris*		14					9			21	50		24			17	20				
Senna artemisioides subsp. *zygophylla*										7											
Campanulaceae																					
Isotoma petraea									33												
Wahlenbergia communis				100		13			11												
Wahlenbergia gracilis						13							6								
Wahlenbergia stricta	25	71	20		33	50	27		67	7			29		17		20				25
Caryophyllaceae																					
**Polycarpon tetraphyllum*		14	10			13															13
Scleranthus pungens									?												
**Spergularia rubra*	50		20														40	50			38
Casuarinaceae																					
Casuarina pauper							91			14											
Chenopodiaceae																					
Atriplex acutibractea subsp. *acutibractea*					?																
Atriplex angulata	25		10				9									17					
Atriplex conduplicata			10															25			
Atriplex eardleyae	25	43				25	27						18		17				20		25
Atriplex holocarpa	75		50			13	36					100				50	60	75	80	100	50
Atriplex leptocarpa	25		20	100														25			
Atriplex limbata			20			13	9	25					53		17						13
Atriplex lindleyi	25		30	100			18								17	50	40	25	60	100	25
# Atriplex lobativalvis																					
# Atriplex nessorhina																					
Atriplex nummularia	25													100			20				
Atriplex stipitata	50	29	30			25	36	100		64	50		71		33	50					38
Atriplex suberecta	50		30																		
# Atriplex turbinata																					
# Chenopodium album*																					
Chenopodium cristatum		29	10		33	38	18	25	33	21			12						40		25
Chenopodium curvispicatum	25	71	10		100	38	73		22	36			41		50						50
Chenopodium desertorum					67	13	9	50			50		6								13
Chenopodium melanocarpum																					?
**Chenopodium murale*	25																				25
#Chenopodium pumilio																					
# Dissocarpus biflorus var. *biflorus*																					
# Dissocarpus biflorus var. *cephalocarpus*																					
Dissocarpus paradoxus		14	10			25	9	25		14	50		18				20				25
Einadia nutans	100	100	50	100	100	75	27	50	44	50	50		65		67		20		20	100	63
Enchylaena tomentosa	75	29	50		67	50	100	100	67	86	50		47			17					100
Halosarcia pergranulata subsp. *pergranulata*	50		30	100			9										40	75		100	
Maireana aphylla							18												40		
Maireana appressa													6					25			

Taxon family & name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Number of quadrats	4	7	10	1	3	8	11	4	9	14	2	2	17	1	6	6	5	4	5	1	8
Maireana brevifolia			10			38							6								25
Maireana coronata						13	9	25					12			17			40		
# *Maireana erioclada*																					
Maireana georgei			10							21			6		17						13
Maireana integra													6								
Maireana pentatropis						13	18			7											13
Maireana pyramidata	25		10	100		13	73	50		29			29	100	100	17			20		50
Maireana sclerolaenoides			10				18									17					
Maireana sedifolia							18								17						
Maireana triptera		14	20		67		45	100	56	64	100		12		17						50
Maireana turbinata								25													
Malacocera tricornis	50			100			27								17	33	20		40		
Neobassia proceriflora			10																		
Osteocarpum acropterum	100		50	100			9					50	6				20	50		100	25
Rhagodia spinescens		14	10			50	36	25	11	29			47			17					25
Salsola kali var. *kali*	50	43	50	100	33	38	73	75	11	50	50		53	100		17	20	25			63
Salsola kali var. *strobilifera*					33					7	50		6		17	17					25
Sclerolaena articulata													6								
Sclerolaena bicornis var. *bicornis*							18			7	50		29			17	20		40		13
Sclerolaena blackiana													6								
Sclerolaena brachyptera			10				9												40		
Sclerolaena convexula		14			33				89	7	50		6								
Sclerolaena decurrens			10										6		17						
Sclerolaena diacantha		14	20		67	13	36	25	11	21	50		65		17				20		38
Sclerolaena divaricata			10				18				50	50	6		33	33	20	25		100	13
Sclerolaena eriacantha			10				9			7											
Sclerolaena intricata	100		50	100		38	73	100		57	50	50	71	100	67	100	60	25	80		75
Sclerolaena johnsonii													6								
Sclerolaena lanicuspis									11				29								25
Sclerolaena longicuspis																17					
Sclerolaena muricata																	20				13
Sclerolaena obliquicuspis		14	10			25	27			7			18		17	17					25
Sclerolaena oppositicuspis				100									6								
Sclerolaena parallelicuspis							?	?		?					?						
Sclerolaena patenticuspis							?								?						
Sclerolaena stelligera												50					20				
Sclerolaena tricuspis							9			7			12				20		40		
Sclerolaena ventricosa	25			100											17			25	20		
Convolvulaceae																					
Convolvulus erubescens	25	29	20		100	38			44	36	50		65		83	50			20		63
Crassulaceae																					
Crassula sieberiana									22												
Cucurbitaceae																					
Citrullus lanatus var. *lanatus*						13									17						
Cucumis myriocarpus			10										6	100							
Euphorbiaceae																					
Chamaesyce australis																	20				
Chamaesyce drummondii	25			100					11							17					13
Euphorbia drummondii		14	10		33	13			44	21		50	18		50		20		40		
Euphorbia eremophila									22	7					33						
Euphorbia stevenii													6		17						
# *Phyllanthus involatus*																					
Phyllanthus lacunarius									11				6		17						25
Fabaceae																					
Cullen cinereum			10																		25
Cullen parvum										7											
Glycine clandestina		43	10							7											
Glycyrrhiza acanthocarpa			10										6								
Indigofera australis									33												
Lotus australis			10																		
Lotus cruentus	25												12		33		20				
Lysiphyllum carronii																					13
Medicago laciniata								25	11												
Medicago minima		14				25							12								
Medicago polymorpha		29				13											20				
* *Medicago truncatula*																			?		?
Muelleranthus trifoliolatus			10																		
Swainsona affinis				100	33				11	21						17	40	25	40		
Swainsona campylantha						13	18						29		17	17			80		13

Taxon family & name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Number of quadrats	4	7	10	1	3	8	11	4	9	14	2	2	17	1	6	6	5	4	5	1	8
Swainsona greyana															17						
Swainsona microphylla													6								
Swainsona oligophylla	25																	50			
#*Swainsona phacoides*																					
**Trifolium cernuum*								25		7											
Frankeniaceae																					
Frankenia species																?		?	?		
Gentianaceae																					
**Centaurium spicatum*			10																		50
**Centaurium tenuiflorum*									11									25			
Geraniaceae																					
**Erodium cicutarium*						13				7											
Erodium crinitum									11	7	50										
Goodeniaceae																					
Goodenia fascicularis															17	17					13
Goodenia glauca	?	?	?		?																
Goodenia heterophylla subsp. *heterophylla*																					
Goodenia lunata									11												
Goodenia pinnatifida										7											
Scaevola spinescens			10				9			7							20				
Haloragaceae																					
Haloragis aspera			10			13															25
# *Haloragis glauca*																					
Haloragis odontocarpa									11				6								
Myriophyllum verrucosum																					13
Lamiaceae																					
Mentha australis		29																			13
Prostanthera striatiflora									56												
**Salvia verbenaca*		29				25	9		11	7	50										13
Teucrium racemosum	25	29	40	100		25	9					100	18				60	50		100	25
Lentibulariaceae																					
Utricularia dichotoma																				100	
Linaceae																					
Linum marginale		?				?															
Loranthaceae																					
Amyema lucasii										14											
Amyema maidenii subsp. *maidenii*					33				44	7			6								
Amyema miraculosum subsp. *boormanii*		?			?			?	?				?								
# *Ameyema quandong*																					
Lysiana exocarpi							9						6								
Lysiana murrayi									33				6								
Malvaceae																					
Abutilon fraseri									11				6								
Abutilon leucopetalum		29	20		33			25	22	14			12		17						13
# *Abutilon otocarpum*																					
Hibiscus brachysiphonius			10				9		22						17	33			40		13
Hibiscus sturtii var. *grandiflorus*									11												
# *Hibiscus sturtii* var. *sturtii*																					
Lavatera plebeia	25	14				25															
**Malva parviflora*	25	29	20			38						50	6				20				63
**Malvastrum americanum*	25	71	20	100		38	9			7	50		12		17				40		75
Sida ammophila									?	?				?	?						
Sida corrugata	25					25	9		33	36	50		12								25
Sida cunninghamii			10			13	9		44	29			6		17	17					25
Sida fibulifera		14																			
Sida intricata		29		100		13	9			7	50		41	100	50		20		20		50
Sida petrophila		29	20		33		9		22	14			6								
# *Sida rhombifolia*																					
Meliaceae																					
**Melia azedarach*																					13
Owenia acidula																17					
Mimosaceae																					
Acacia aneura		29			100	25	27	75	78	71	50		35								13
Acacia brachystachya									44												
# *Acacia hakeoides*																					
Acacia ligulata		29								7			6								

Taxon family & name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Number of quadrats	4	7	10	1	3	8	11	4	9	14	2	2	17	1	6	6	5	4	5	1	8
# *Acacia loderi*																					
Acacia oswaldii						13	18			21	50										38
# *Acacia salicina*																					
Acacia stenophylla	50		60			13											40				
Acacia tetragonophylla		14			33	25	9	25	67	43			18								13
Acacia victoriae		57	20			50	9			14	50		59		17				20		63
Myoporaceae																					
Eremophila bignoniiflora							9														13
Eremophila deserti											50		6								
Eremophila duttonii			10		33		9	50	33	43			6								13
Eremophila gilesii										?											
Eremophila latrobei						13			11	7											
Eremophila longifolia		29	10	100	67	25			33	64	50		24								25
Eremophila maculata													12				20				13
Eremophila polyclada							9														
Eremophila serrulata									33	7											
Eremophila sturtii		14	10			38	18	75		29	100		29		17	17					13
Myoporum montanum	100	86	20			63	45			7	50		24					25			88
Myoporum platycarpum													6								
Myrtaceae																					
Eucalyptus camaldulensis	75	100	10			13														100	38
Eucalyptus coolabah subsp. *coolabah*			?																		
Eucalyptus intertexta					100	13			11	7											
Eucalyptus largiflorens	50		80																		
Eucalyptus ochrophloia				100																	
Eucalyptus populnea subsp. *bimbil*		43				100															
Nyctaginaceae																					
Boerhavia dominii		14	10	100	33	38			33	14			18						20		13
Oleaceae																					
Jasminum lineare		14							11		50										13
Onagraceae																					
Epilobium hirtigerum			10																		
Oxalidaceae																					
Oxalis corniculata		57	10		67	50	9		78	36	50		41			17					38
Oxalis perennans													6								
* *Oxalis pes-caprae*																					?
Papaveraceae																					
**Argemone ochroleuca* subsp. *ochroleuca*						13															
**Glaucium corniculatum*																					13
Pittosporaceae																					
Pittosporum phylliraeoides			10			13															38
Plantaginaceae																					
Plantago cunninghamii									11												
Plantago drummondii		14			33	25	9		56	7	50		24		33	33		25	80	100	25
Plantago turrifera											50										
Plumbaginaceae																					
* *Limonium lobatum*																					?
Polygonaceae																					
Acetosa vesicaria		14																			
**Emex australis*		14				13							6								13
Muehlenbeckia florulenta	75		70	100								100			17	17	80	50			13
Persicaria lapathifolia						13															13
Persicaria prostrata	?	?		?																	
**Polygonum aviculare*																					13
Rumex brownii			10																		
**Rumex crispus*		14																			
Portulacaceae																					
Calandrinia eremaea							9			14											
# *Calandrinia ptychosperma*																					
# *Portulacca intraterranea*																					
Portulaca oleracea			10			13	18	25	11	7			18		17	17	40		20		50
Primulaceae																					
**Anagallis arvensis*	25	57				50	9		22				12				20				63

Taxon family & name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Number of quadrats	4	7	10	1	3	8	11	4	9	14	2	2	17	1	6	6	5	4	5	1	8
Proteaceae																					
Grevillea striata		14			67	13		50	44	29			18								
Hakea leucoptera															17						
Hakea tephrosperma					33						100										
Ranunculaceae																					
# *Clematis microphylla* var. *microphylla*																					
Rubiaceae																					
Canthium odoratum									33												
Canthium oleifolium					?		?		?	?											
Rutaceae																					
Eriostemon linearis									22												
Flindersia maculosa		14				13	18	100		36			18								
Geijera parviflora						?	?														
Santalaceae																					
Santalum lanceolatum			10						22				6								
Sapindaceae																					
Alectryon oleifolius		14			33	13	45	50		21			6								13
Atalaya hemiglauca		14	10						11	7											50
Dodonaea viscosa subsp. *angustissima*		14							11	21	100		18		33						
Scrophulariaceae																					
Mimulus repens	25																				
Stemodia florulenta	50		10														20				
Solanaceae																					
Datura leichhardtii																					?
Lycium australe																					13
**Lycium ferocissimum*		57			33	25	9			7											38
**Nicotiana glauca*	25		20																		
Nicotiana suaveolens	25																				
Nicotiana velutina	100	29	60		33	25	9		22				12	100	17						25
Solanum ellipticum		43	10	100	100	25	27		78	64	100		18			33					25
Solanum esuriale		29			33	25			11	14	50		41		17	17			40		25
Solanum ferocissimum								25	11	7	50										
**Solanum nigrum*		43	30			25	9		11				6								50
Thymelaeaceae																					
Pimelea microcephala subsp. *microcephala*		14			67		9						6								
Pimelea trichostachya			10						11	7					17						
Verbenaceae																					
**Verbena officinalis*			10																		13
**Verbena supina*			20																		25
Violaceae																					
Hybanthus monopetalus					?																
Zygophyllaceae																					
Zygophyllum ammophilum	14	10				33	25							7					12		
Zygophyllum eremaeum																	6				
Zygophyllum humillimum														?							
Zygophyllum iodocarpum														7					6		
Zygophyllum ovatum						13															

Germination and *ex situ* storage of *Hakea dohertyi* (Proteaceae) seed

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Abstract: Fresh seeds of the endangered *Hakea dohertyi* Haegi (Proteaceae) germinated at 15°C (with 12 hour light) within 14 days. At higher temperatures (20°, 25°C) seeds were slower to germinate. After 28 days only 5% of seeds germinated at 30°C, but when moved to 15°C, close to 100% of seeds germinated within 14 days. Having established optimum germination conditions, the effects of *ex situ* storage conditions and duration were examined. Storage at low moisture content appeared to have little effect on the germinability of *Hakea dohertyi* seeds and this species can be considered orthodox in that respect. Seeds stored at 4.5 or 9% moisture content, 5 or -20°C and tested after 1 and 7 years of storage achieved close to 100% germination. Issues relating to the *in situ* and *ex situ* conservation of *Hakea dohertyi* are discussed.

***Cunninghamia* (2003) 8(1): 129–132**

Introduction

There is a high degree of diversity and local endemism in the Proteaceae of the Sydney region (Myerscough et al. 2000). *Hakea dohertyi* Haegi, discovered in 1986, is one of a number of endangered endemic species occurring in the region that are threatened by land management changes (Fisher et al. 1995). It is an obligate seeding, bradysporous species mainly restricted to an 18 km² area around the Kowmung River in Kanangra Boyd National Park (Benson & McDougall 2000) (Figure 1). Less than 7000 individuals are found in this area and the disjunct Burragorang (Tonalli Cove) population, of less than 100 individuals could be threatened by changes in water level of the nearby Warragamba dam. Other threats to the species include very hot (>300°C) or prolonged fires (>3 min.) that kill seeds (Steenbeeke 1995), and goats may eat young plants (Benson & McDougall 2000). Juvenile and adult plants are killed by fire (Steenbeeke 1995) and this may affect the survival of such species in the event of a once-off high intensity fire that can kill both plants and canopy stored seed, or frequent low-level fires that kill juvenile plants (Myerscough et al. 2000).

Hakea seeds are generally non-dormant and begin to germinate in 15–100 days at temperatures between 15° and 28°C (Fox et al. 1987, Wrigley & Fagg 1989, Elliot & Jones 1990). Steenbeeke (1995) observed that fresh seed of *Hakea dohertyi* is very viable, demonstrating almost 100% viability in bench germination tests (temperature and light conditions were not specified). Seeds of this species stored in 'room conditions' lose viability over time; viability appears to drop after 1 year (Steenbeeke 1995) and seeds are dead after ten years in these conditions (M. Doherty pers. comm). Little else is known about the effect of storage conditions on the long-term viability of *Hakea* species *per se* (Hong et al. 1998) although the long viability of the canopy held seed (Steenbeeke 1995) indicates potential for successful long-term storage *ex situ*. This study was conducted to investigate the specific temperature requirements for germination of *Hakea dohertyi* seeds and to identify the *ex situ* storage potential of seeds of this species.

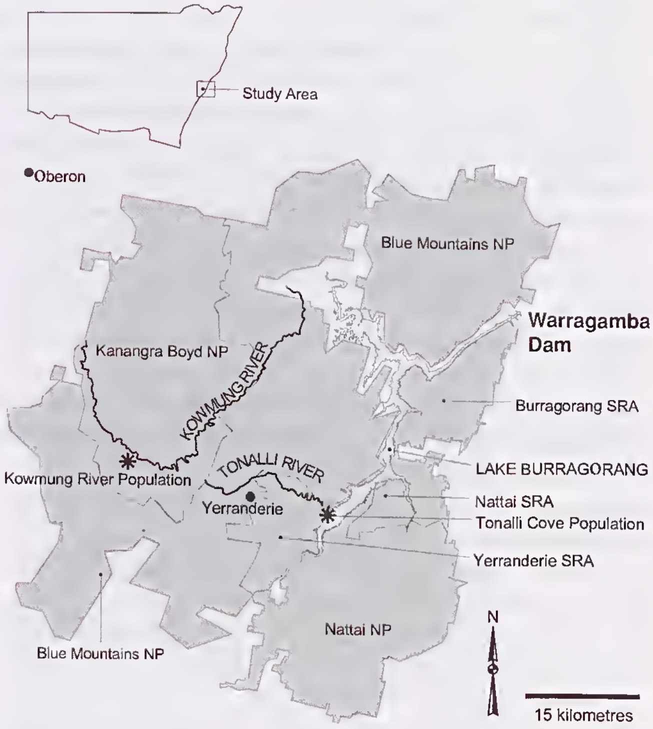

Fig. 1. Locations of *Hakea dohertyi* populations, in Warragamba catchment area, used in this study.

Methods

Seed collection and processing

Composite collections of seeds were made from a range of trees at the small Tonalli Cove population (Lake Burragorang) in June and December 1995 and from the larger Kowmung River population in May 1996 (Figure 1). No more than 10% of the seed held on the trees was collected at any time. The seeds were used fresh or were dried at room temperature and stored in the range 7–9% moisture content (MC), measured gravimetrically using the fresh weight. Some seeds from the Kowmung River were also dried over silica gel to 4.5% MC. The seeds dried to 4.5 or 9%M were then stored at 5°C or -20°C in sealed foil packets in the NSW Seedbank at Mount Annan Botanic Garden. These storage conditions were as close to the International Seed Testing Standard as possible (Cromarty et al. 1990). The following experiments were performed only on *Hakea dohertyi* seeds from the Kowmung population because of the larger number of seeds collected from that site.

Optimum temperature for germination

Freshly collected seeds were sown onto a sheet of Whatman's No. 1 filter paper over a bleached circle of terry towelling material to maintain moisture (distilled water) close to seeds. There were 80 seeds for each treatment split between eight 70 mm petri dishes. Temperatures of 15, 25 and 30°C were supplied by growth cabinets (Lindner and May Pty Ltd) and all seeds received 12 continuous hours of light in a diurnal period. Seeds were monitored daily for germination, deemed to have occurred when 2 mm of radicle had emerged.

Seed Storage requirements

After one and seven years of storage, seeds from the four treatments (4.5 or 9% MC and 5°C or –20°C) were subjected to optimal germination conditions determined in the first experiment, viz. eight replicate dishes of ten seeds per treatment were placed randomly in a 15°C controlled temperature cabinet (12 hr light). Prior to the commencement of germination conditions, seed packets were opened and seed moisture was allowed to equilibrate in room conditions for 24 hr, to avoid imbibition injury (Ellis et al. 1985). Seed germination was recorded as before.

Table 1. Effects of storage conditions (temperature and seed moisture content [MC]) and duration of storage on germination of *Hakea dohertyi* seed (± s.e.)

Years of storage	Storage conditions			
	5°C		-20°C	
	4.5% MC	9% MC	4.5% MC	9% MC
	First germination (mean days)			
1	13.9 ± 0.3	13.0 ± 0.0	13.2 ± 0.2	12.9 ± 0.2
7	12.2 ± 0.2	12.2 ± 0.2	12.4 ± 0.3	12.0 ± 0.0
	50% germination (mean days)			
1	15.6 ± 0.4	14.7 ± 0.5	15.2 ± 0.4	15.9 ± 0.3
7	14.1 ± 0.3	14.2 ± 0.3	14.4 ± 0.2	14.2 ± 0.3
	Final germination %			
1	97.5 ± 1.6	100.0 ± 0.0	100.0 ± 0.0	97.5 ± 2.5
7	98.7 ± 1.2	96.2 ± 2.6	98.7 ± 1.2	100.0 ± 0.0

Results

Climatic regime

The climate in the area is characterised by average maximum summer temperatures of between 20° and 25°C and winter minimums less than 5°C and down to -2°C (figure 2, Bureau of Meteorology 2002). Rainfall is up to 170% higher in summer than in winter, with a monthly average of between 40 and 100 mm.

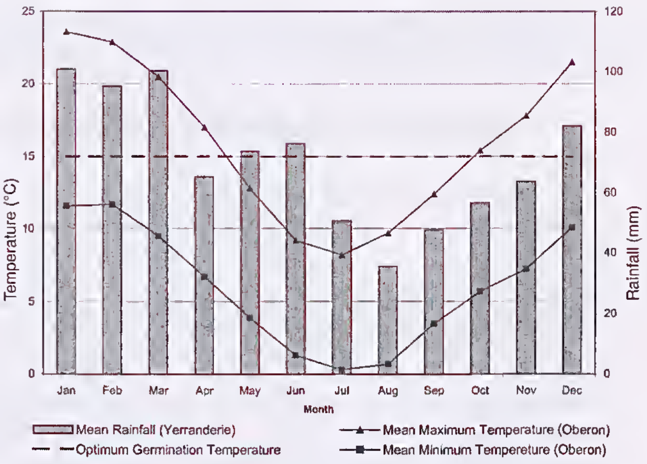

Fig. 2. Climatic averages for the closest available meteorological stations to *Hakea dohertyi* (temperature, Oberon 1991–2002; rainfall, Yerranderie 1908–1979).

Optimum temperature for germination

Germination proceeded most rapidly at 15°C (Figure 3). Maximum seed germination occurred within 14 days at this temperature, while seeds at 25°C took more than 28 days to achieve maximum germination. At 30°C germination proceeded very slowly with less than 5% of seeds germinating in the first month. When seeds were moved from 30°C to 15°C, germination proceeded relatively rapidly, with the majority of seeds germinating after two weeks at the lower temperature.

Seed storage requirements

The tested storage conditions and duration appeared to have little effect on seed germination of *Hakea dohertyi* (Table 1). The number of days to first germination appeared to have been slightly slower when compared with data from the optimisation experiment (not statistically tested), but 50% germination was achieved within 16 days, and final germination percentages were at or near maximum.

Discussion

This work confirms the Steenbeeke (1995) observation that canopy stored seed of *Hakea dohertyi* has high viability. The seed germination pattern of *Hakea dohertyi* under different temperature regimes is similar to other woody Grevilleoideae species including *Hakea* (Fox et al. 1987, Lamont & Groom 1998). The high germinability of seeds at 15°C, compared with the other temperatures, shows that this temperature is within the optimum range for laboratory germination, and indicates that seeds are most likely to germinate *in situ* during times of moderate temperature when moisture is available for germination and seedling establishment. This 'temperature sensing' strategy is typical of many species from the Mediteranean climatic regions of Australia (Bell 1999). Steenbecke (1995) predicted that most germination would occur in the cooler months from May to August but observed that seeds are dropped at all times of the year, due to follicle opening as a result of secondary thickening (this species is not strongly bradysporous as it holds some but not all of its seeds on the plant for extended periods). Although rainfall in the area where *Hakea dohertyi* grows is generally lower during winter and early spring than in summer and autumn

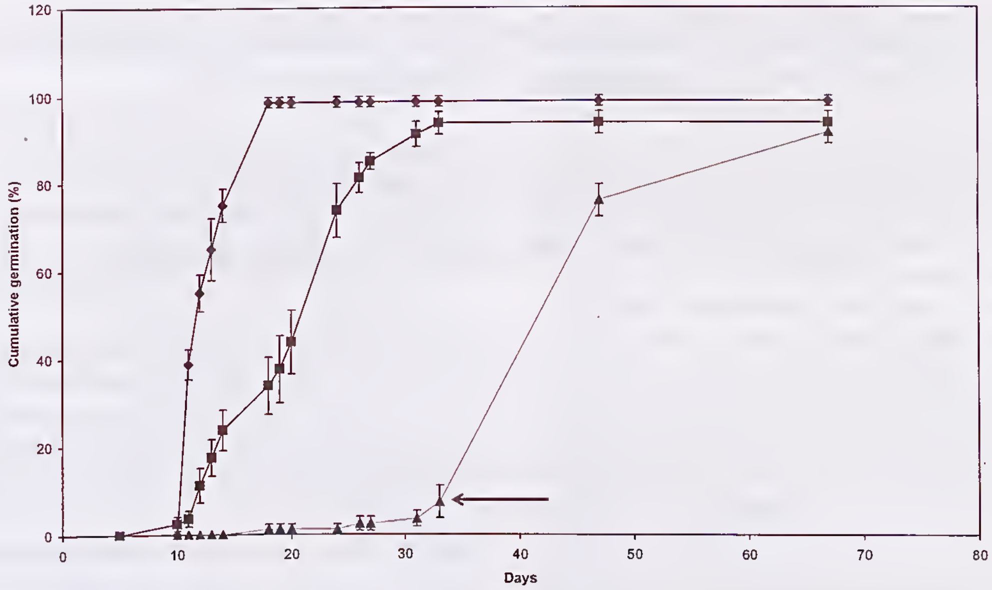

Fig. 3. Effect of temperature on germination of freshly collected seeds of *Hakea dohertyi*. ◆ 15°C, ■ 25°C, ▲ 30°C. Arrow indicates that seeds in the 30°C treatment were moved to 15°C on day 34. Vertical bars represent standard errors of the means.

(Figure 2), average rainfall even in the driest month (August) exceeds 35 mm. As a result, given lower evaporation rates than in summer, sufficient moisture may be available for germination. It is less likely that dehisced seeds of *Hakea dohertyi*, would germinate during hot summer conditions (>25°C) when they may quickly lose viability, be predated or rot in wet or humid conditions.

Hakea dohertyi is listed as an Endangered Species under the NSW *Threatened Species Conservation Act* 1995 and an understanding of its fire ecology is essential for *in situ* management. The last recorded fire affecting *Hakea dohertyi* populations in the region was in 1957, but little is known about its effects. Steenbeeke (1995) observed that some plants appeared not to have been affected by this fire and that across populations there was an uneven spread of age classes resulting from recruitment from dehisced seed in the absence of fire. *Hakea* species differ in the degree to which they retain seed in the canopy (Lamont & Groom 1998), but the survival of seeds within the fruit following fire is greater as fruit size increases (Bradstock et al. 1994). Steenbeeke (1995) found that seeds of *Hakea dohertyi* are killed when fruit are subjected 300°C for only 1 min making canopy-held seed of this species very vulnerable to fire. While there is potential for seedling recruitment from spontaneous leakage of bradysporous seed, young plants of such species may be predated (Bradstock 1985 quoted from Myerscough et al. 2000) and are vulnerable to fire (Steenbeeke 1995). The greatest potential threat to populations of *Hakea dohertyi*, and other bradysporous obligate-seeding species, is local extinction from a series of frequent fires, when fire intervals are less than the juvenile period (Gill & Bradstock 1995). In *Hakea dohertyi* the juvenile period is not less than 5 years (Steenbeeke 1995). Recruitment of seedlings after any fire is unpredictable due to variability and unpredictability of post-fire weather conditions.

Given that there is adequate moisture, temperature appears to be the main factor controlling germination of *Hakea dohertyi* seeds. This species appears typical of many other bradysporous Grevilleoideae in that their seeds do not display physical or physiological dormancy (Myerscough et al. 2000) and, as with other species with canopy-stored seed, probably have only a small or no soil-seedbank (Baskin & Baskin 1998). Canopy stored seed of some species such as the South African *Protea compacta* may exhibit dormancy on release from the infructescence (Brown 1993, Dixon et al. 1995)(such dormancy was previously not recognised by authors such as Bell et al. (1993), possibly because of the age of the seed, which was no longer dormant, or some other unrecognised factor). There is a possibility that the seeds used in this experiment have been smoke-primed *in situ* or that the seed is no longer dormant due to the length of time it has been on the plant. We propose that smoke priming may take place in many species in the Sydney region that are not directly affected by fire, due to the levels of dormancy-breaking substances contained in the air following major fire events in and around the region fulfilling this function. Confirmation of this proposal is required by monitoring fire events and stored-seed germination responses, although canopy stored seed is less likely to be as affected as soil seed bank stored species (Lamont & Groom 1998). It would also be useful to investigate the effects of various combinations of heat shock and smoke on a wider range of Proteaceae species of the Sydney region as these factors have been shown to greatly affect germination patterns of seeds of some species (Edwards & Whelan 1995, Kenny 2000, Morris 2000).

Hakea dohertyi has orthodox seed storage behaviour, that is, by the definition of Roberts (1973), it can withstand desiccation and can therefore be stored *ex situ*. This storage behaviour is an advantage for long-term storage of seeds for conservation or other purposes. Storage of seeds in a desiccated condition appeared to have only a small effect on the speed of germination, when compared with fresh seed, and did not decrease viability of seed, as distinct from storage under room conditions. While the results indicate a slightly decreased speed of germination after 7 years, we are cognizant of the inherent difficulties when conducting longitudinal studies, even when using essentially identical treatments (Morrison & Morris 2000). Taking comparison differences into account, it is still clear that seed of this species remains viable after at least seven years of storage at a range of moisture contents and temperatures. That viability did not drop dramatically from the time of collection to the 7-year test indicates that this species may well remain viable for many more years under quite simple storage conditions. Indeed, Steenbeeke observed more than 80% viability of 15-year-old canopy-stored seeds of *Hakea dohertyi* indicating the potential for very long *ex situ* storage periods. Seeds may be dried to between 4.5 and 9% moisture montent, and stored in a domestic fridge (~5°C) or freezer (~-20°C), preferably the latter as this will give the best storage life in the long term. Although not specifically tested for *Hakea dohertyi*, our experience with many other species is that the low seed moisture levels must be maintained over time. It is obvious that moisture content within the range tested would be adequate, but for long-term storage, the moisture content should be 5 ± 1% (Cromarty et al. 1990). Maintenance of moisture content is most easily achieved by storage in a hermetically sealed container or, as in this case, in vacuum heat-sealed foil packets routinely used at the NSW Seedbank.

While it is possible to store *Hakea dohertyi* seeds, *ex situ* seed populations cannot substitute for natural populations. Translocation of threatened species is not a highly successful conservation strategy (ANPC 1997, Hogbin 2002). Seed-banking of endangered species is only a minor conservation measure, in terms of maintaining diversity of natural populations. Rather, it gives us the opportunity to research, display and educate on the importance of *in situ* conservation. Fortunately, at this time, there is little evidence that this species is greatly threatened by current *in situ* management practices but an intense or frequent fire regime, would be seriously detrimental to the survival of *Hakea dohertyi*.

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Pollination ecology of *Tetratheca juncea* (Tremandraceae): finding the pollinators

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Abstract: *Tetratheca juncea* Smith (family Tremandraceae) is a terrestrial herbaceous plant now mainly found in the Lake Macquarie area of coastal NSW and listed as Vulnerable under Schedule 2 of the NSW *Threatened Species Conservation Act* 1995. This study carried out from July 2001 to June 2002 records the observation and identification of two species of native bee buzz-pollinating its flowers and describes a direct relationship between the first appearance of a pollinator and the commencement of seed set. Findings from this study with respect to the pollination ecology of *Tetratheca juncea* are:

- There is a strong flowering period from September to January, though a number of flowers can be found on some plants across the geographic range of the plant in all months of the year;
- Two species of native bee *Lasioglossum convexum* and *Exoneura* sp, were confirmed collecting pollen from the flowers by way of buzz pollination;
- Fruiting only occurred in coincidence with flower pollination by these bees;
- Flowering, seed set and seed release was a concurrent process while ever the bees were active;
- The bees are polylectic and the sexual reproductive process in *Tetratheca juncea* appears to be pollinator-limited.

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Introduction

Tetratheca juncea Smith (Tremandraceae) is a terrestrial herbaceous plant endemic to NSW. It is listed as Vulnerable under Schedule 2 of the NSW *Threatened Species Conservation Act* 1995, as Vulnerable in the *Commonwealth Environment Protection and Biodiversity Conservation Act* 1999 and has a ROTAP coding of 3VCa (Briggs & Leigh 1995). *Tetratheca juncea* is now known only from Wyong to Bulahdelah and inland to the edge of the main ranges with the greatest concentration of records being from the Wyong and Lake Macquarie local government areas (Payne 2000). There species was recorded in what are now suburbs of Sydney in the late 19th Century, from Port Jackson and suburbs to the south (Thompson 1976) but is now regarded as extinct there.

In the Munmorah area *Tetratheca juncea* grows in low open forest in association with *Angophora costata*, *Eucalyptus capitellata*, *Eucalyptus haemastoma* and with a mixed shrub and grass ground cover (Payne 1993). Payne (2000) concluded that the preference for the plant was that of Munmorah Conglomerate geology with the Awaba Soil Landscape Unit and that the plant showed a preference for dry ridges and shade. Table 1 shows the number of records for 400 records of *Tetratheca juncea* sites compiled from published and unpublished surveys (Payne 2000, Bartier et al. 2001, and S. Bell & C. Driscoll unpublished) in vegetation communities occurring within the Lower Hunter and Central Coast (LHCCREMS) (NPWS 2000, Eco Logical Pty Ltd 2002).

Table 1. Distribution of reports of *Tetratheca juncea* across vegetation map units in the Lower Hunter and Central Coast.

Description	Map Unit	Percentage
Coastal Plains Smoothbarked Apple Woodland	MU 30	62%
Coastal Plains Scribbly Gum Woodland	MU 31	14%
Coastal Foothills Spotted Gum-Ironbark Forest	MU 15	10%
Alluvial Tall Moist Forest	MU 5	2%
Heath	MU 55	2%
Lower Hunter Spotted Gum-Ironbark Forest	MU 17	1%
Wyong Paperbark Swamp Forest	MU 43	1%
Coastal Sheltered Apple-Peppermint Forest	MU 11	1%
Coastal Sand Wallum Woodland-Heath	MU 34	1%
Swamp Mahogany-Paperbark Forest	MU 37	1%
Riparian Melaleuca Swamp Woodland	MU 42	1%
Coastal Clay Heath	MU 48	1%
Coastal Wet Sand Cyperoid Heath	MU 44	<1%
Coastal Wet Gully Forest	MU 1	0.5%
Coastal Sand Apple-Blackbutt Forest	MU 33	0.5%
Hunter Valley Moist Forest	MU 12	<0.5%

GIS analysis of regional distribution of records against 1:250 000 geological maps (Environment Australia) shows that *Tetratheca juncea* plants have been found growing on following underlying geologies: Quaternary Sands; Triassic Sandstones; Triassic Shales; Permian Coal Measures and Carboniferous Volcanics.

Tetratheca juncea is distinguished from other members of the *Tetratheca* genus by having generally leafless stems that have a distinctly angular, winged structure (Thompson 1976). The flowers however share the four-petalled, pink form that is characteristic of the genus (although, during this study, flowers with 5, 6, and 7 petals proportionately arranged were recorded). The flowering period is generally reported as being from mid to late winter through to late summer (Gardner

& Murray 1992). The flowers grow from nodes on the mostly leafless stem and are commonly solitary, but occasionally in pairs with each flower facing downward, suspended on a peduncle of about 10 mm length. The four petals range in colour from mauve through pink to almost white (Thompson 1976). There are eight dark mauve poricidal anthers surrounding the carpel with the stigma protruding beyond their length (Bartier et al. 2001). Payne (2000) describes the anthers as containing the pollen in a basal sac with Bartier et al. (2001) also noting that the pollen is contained basally in tapetal fluid.

Reproduction in *Tetratheca juncea* is through both asexual rhizomal spread and sexual pollination, seed development and germination (Payne 2000). Bartier et al. (2001), using hand pollination, showed that while the plant is capable of autogamy, the quantity of seed development was far greater with outcrossing. The potential for autogamous seed set was considered to be low because of the pendant presentation of the flowers. Recruitment by seed appears to be limited by a dispersal mechanism involving ants collecting the seed, for the lipid-rich elaiosome (Brew et al. 1989, Boeswinkel 1999).

Pollen vectors of *Tetratheca juncea* have not been described to date despite considerable effort. Bartier et al. (2001) spent almost 100 observation hours in set periods of 15–25 minutes, but did not observe any insects collecting pollen from the flowers. Payne (2000) proposed that a Carpenter Bee could extract pollen from the flowers by way of vibration, or that pollen might simply dry in the anthers and fall out with some grains lodging on the stigma. Hingston (1999) in southern Tasmania, collected *Lasioglossum* species and *Homalictus niveifrons/megastigmus* from the flowers of *Tetratheca glandulosa*. Bartier et al. (2001) proposed that a buzz-pollinator for *T. juncea* could be members of the *Homalictus* genus and possibly *Homalictus megastigmus*. The aim of this investigation was to determine the identity and behaviour of pollen vectors involved in the sexual reproductive process for *Tetratheca juncea*.

Methods

Stamen and anther detail

In order to better understand the mechanism for pollen removal, details of the stamens and their arrangement in the developing flower were examined using dissecting, compound and scanning electron microscopes (SEM).

Field observation for pollinators

Fieldwork was carried out at Wakefield, near Toronto (Figure1) where there were large populations of *Tetratheca juncea* extending over a wide area. Two populations were selected: Site 1 had about 200 plants growing within an area of approximately one hectare and Site 2, about one kilometre southeast of Site 1, had around 50 plants within an area of approximately 50 × 25 metres. The habitat of the *Tetratheca juncea* here had a low grassy ground cover with a sparse shrub cover that facilitated observer movement around the populations, and allowed observation of a wide area from any one position. Each site contained some large patches of *Tetratheca juncea* plants in dense flower and the sites were surrounded by many hectares of relatively undisturbed forest. Plant names follow Harden (1992–2002)

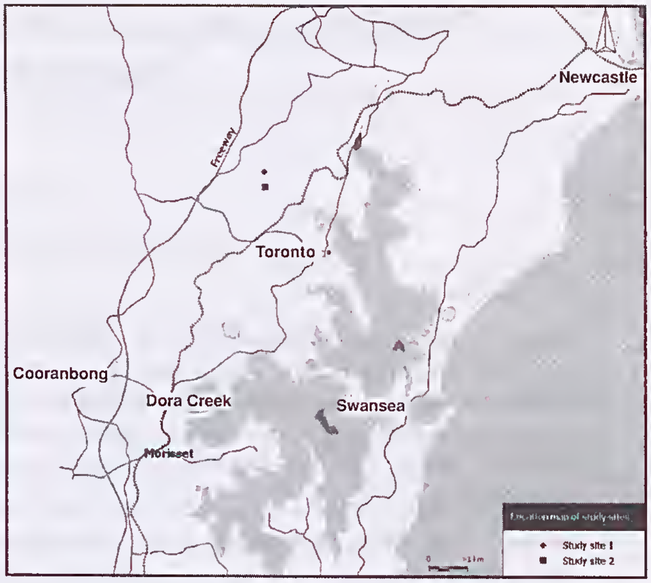

Fig. 1. Location of the study sites

A basic premise at the start of this study was that the amount of pollen available from *Tetratheca juncea* flowers would be so small as to only provide a satisfactory reward-for-effort to a small insect and that the search for a pollinator would require very close observation. Within both sites, areas with the greatest density of flowers were given the closest attention, commencing at the start of flowering in July 2001. Initially, because nothing was known about the behaviour of, or type of pollinators of *Tetratheca juncea*, each site was continuously walked (with arbitrary changes of direction) over a period of two to three hours at a time. Effort was limited to days where the weather was fine and with no more than a light breeze. The start time each day varied and was the time by which any dew on the flowers had finally evaporated. These conditions allowed for up to three observation periods per week. This was done from August 2001 to November 2001 with more general monitoring continuing after that period.

Once a pollinator had been observed at either site, attention was directed towards dense patches of flowers and these were watched for up to two hours continuously and bees were captured for identification. The vegetation surrounding the *Tetratheca juncea* flowers made capture of the bees with nets impractical. Instead bees were captured by clamping a flat lid over the flower with the bee attached, on to a container about 75 mm wide, so capturing bee and flower together. The bees, still in the containers in which they were captured, were placed briefly in a deep freeze and then kept in a refrigerator. Dr Michael Batley of Macquarie University Division of Earth and Life Sciences and who is also associated with the Australian Museum Entomology Department provided the identification of the bees and the pollen that they carried.

Because the bees are out of sight under the flower when extracting pollen, an Anabat II bat-call detector (Titley Electronics, Murwillumbah) set on Division Ratio 4 (not an application the makers would have envisaged) was used to 'listen' for the characteristic buzz of the bees extracting pollen. A major advantage of the Anabat device over straight audio recording was the elimination of the majority of background noise. Using the detector, the buzz was detectable from around half a metre; at this distance it was inaudible to the un-aided ear.

Table 2. Flowering plant species occurring at study Sites 1 and 2.
(Nomenclature follows Harden 1992, 1993, 2000, 2002)

Species	Site 1	Site 2
Acacia ulicifolia (Mimosoideae)	+	+
Billardiera scandens (Pittosporaceae)	+	+
Bossiaea obcordata (Faboideae)	+	+
Comesperma ericinum (Polygalaceae)	+	+
Cryptostylis subulata (Orchidaceae)	+	
Dampiera stricta (Goodeniaceae)	+	
Daviesia squarrosa (Faboideae)	+	+
Dianella caerulea var. *assera* (Phormiaceae)	+	+
Dillwynia retorta (Faboideae)	+	
Epacris pulchella (Epacridaceae)		+
Gompholobium glabratum (Faboideae)		+
Gompholobium minus (Faboideae)		+
Goodenia heterophylla (Goodeniaceae)	+	
Hardenbergia violacea (Faboideae)	+	+
Hibbertia empetrifolia (Dilleniaceae)	+	+
Hibbertia linearis (Dilleniaceae)		+
Hovea linearis (Faboideae)	+	
Leptospermum polygalifolium (Myrtaceae)	+	
Leptospermum trinervium (Myrtaceae)	+	+
Leucopogon juniperinus (Epacridaceae)	+	+
Lomandra glauca (Lomandraceae)	+	
Patersonia glabrata (Iridaceae)	+	
Persoonia levis (Proteaceae)	+	+
Persoonia linearis (Proteaceae)	+	+
Pimelia linifolia (Thymelaeaceae)	+	+
Podolobium ilicifolium (Faboideae)	+	+
Pultenea daphnoides (Faboideae)		+
Tetratheca thymifolia (Tremandraceae)	+	

Results

Habitat associated with Tetratheca juncea

Both study sites were located in an area that was designated as MU 30, Coastal Plains Smoothbarked Apple Woodland (Eco Logical Pty Ltd 2002), and the overstorey tree species present were generally consistent with this designation. The trees present were *Angophora costata* and *Corymbia gummifera* as dominant with *Eucalyptus umbra* and *Eucalyptus capitellata* as co-dominant along with the inclusion of *Eucalyptus piperita*. Table 2 contains a list of all native flowering herb or shrub species that were growing along with the *Tetratheca juncea* at both sites. By far the dominant ground cover were the grasses *Themeda australis* and *Austrodanthonia fulva*; these made up around 90% of the ground cover. All of these species flowered for a time during the flowering of *Tetratheca juncea*. During the observation period the flowering of the plants listed in Table 2 was spasmodic and did not appear to relate to a conventionally described flowering season. The detailed monitoring of the flowering periods of these plants in relation to the flowering of the *Tetratheca juncea* and the pollinator activity is part of a continuing study.

The presence of *Tetratheca thymifolia* was of interest as Payne (2000) comments that at the western extent of its range, *Tetratheca juncea* is replaced by *Tetratheca thymifolia*. In one instance both species were growing together with their stems only a few centimetres apart.

Tetratheca juncea *flower and anther structure*

Inspection of the stamens shows that they are arranged around the gynoecium in four pairs and an examination of the developing flower reveals the reason for this. Each of the four petals is separately folded around two stamens for their length and the outer end of the petal is tightly folded beyond the ends of the anthers so that they are completely enclosed, and they remain this way until anthesis. This arrangement in *Tetratheca juncea* is similar to that described by Thompson (1976) for *Tetratheca hirsuta*.

The stamens themselves consist of a stout filament that merges into the anther which ultimately dehisces through a rostral apical pore (Thompson 1976, Buchmann 1983). The scanning electron micrograph (Figure 2) shows the macroscopic structure and proportions of a single stamen. A cross section (Figure 3) reveals that the internal structure of the anther is made up of four parallel locules with the gametophytic cells that produce the pollen grains lining the walls. Thompson (1976) describes this locular arrangement as generally applying to the *Tetratheca* genus and also notes that the walls between the loci can disintegrate as the anther matures. This disintegration may be the explanation for observations (Payne 2000, Bartier et al. 2001) that the pollen is held in a sac at the base of the anther. During the current study, the integrity of the locular structure of the *Tetratheca juncea* anthers was still apparent in mature flowers. Examination of the anther under a dissecting microscope reveals that it contains pollen in a syrupy tapetal fluid for the full length. This locular structure is similar to that of most angiosperm anthers (Buchmann 1983) during the early stages of development. However, at anthesis most anthers develop parallel or confluent slits for pollen dispersal whereas in *Tetratheca*, pollen release is through the terminal pore. The folding of the petal around the stamens and over the terminal pore appears to serve the purpose of protecting the developing pollen prior to anthesis.

Pollinator observations

As with the Bartier et al. (2001) investigation, this work involved over 100 hours of monitoring; the main difference was the length of continuous time that each monitoring event involved (2–3 hours in contrast to 15–25 minutes by Bartier et al.). Figure 4 shows timing of flowering intensity, bee observations and visits, seed capsule development and seed release during this study.

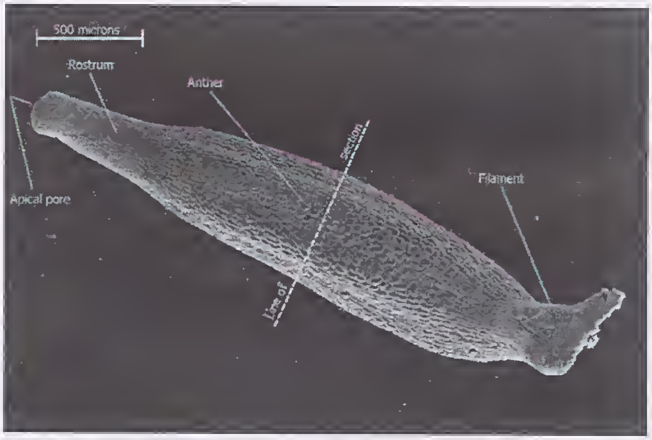

Fig. 2. SEM of one stamen.

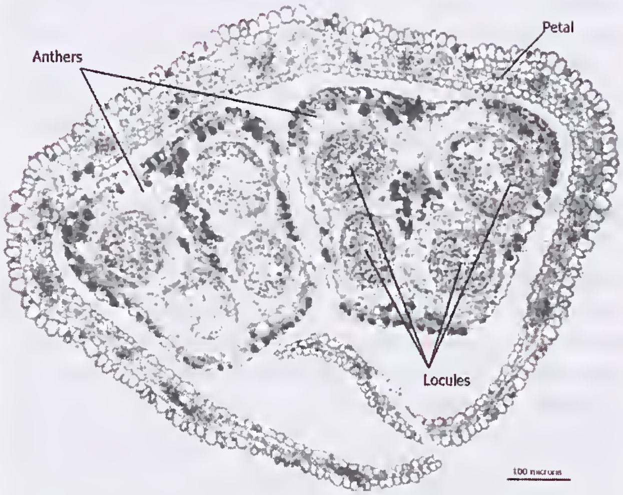

Fig. 3. Mid-section (refer Fig. 2) of a pair of stamens folded in a petal in the unopened *Tetratheca juncea* flower.

A number of insect taxa were attracted to the *Tetratheca juncea* flowers although none did more than hover near the flowers or land on the back of the flower for a brief period. These were Butterfly, *Hesperiidae* (Skipper); Butterfly, *Nymphalidae* (Dingy Ring); Hover Fly, *Syrphidae*; introduced Honey-bee, *Apis mellifera*; Blue-banded Bee, *Amegilla* sp.

On 2 September 2001 at Site 1 a small native bee about 6 mm long was observed to be methodically 'working' through a patch of the *Tetratheca juncea* flowers. The bee would land on the back of a flower and then move to the underside for a few seconds and then fly to another flower. Pollen clumps could be seen on the legs of this bee indicating that it was a female. After attending about six flowers the bee landed nearby and combed the pollen that had been collected. Pollen-combing behaviour was seen often throughout this study. On 24 September 2001 at Site 2 a voucher sample of this bee, identified as *Lasioglossum (Chilalictus) convexum* Walker, was captured on flowers of *Dianella caerulea* var. *assera* flowering among the *Tetratheca juncea* plants. This bee was carrying *Dianella* and *Myrtaceae* pollen but no *Tetratheca juncea* pollen. On 29 September 2001 at Site 2 a different species of native bee, identified as a member of the *Exoneura* genus, and smaller than *Lasioglossum convexum*, was collected while underneath a *Tetratheca juncea* flower. This bee was carrying about 30% *Tetratheca juncea* pollen.

Flowering of *Tetratheca juncea* in the Wakefield population in 2001 commenced at the beginning of July but up until 16 September no seed capsules had developed. The first observation of a native bee collecting pollen was on 2 September and by 16 September the first seed capsules were developing on plants through both observation sites. In one instance a seed capsule developed from a flower from which a *Lasioglossum convexum* bee had been seen collecting pollen. It is interesting to note that no seed development was seen on any of the *Tetratheca thymifolia* plants that were flowering in the immediate area; perhaps the same pollinator limitations apply to both species. At other locations where *Tetratheca thymifolia* was the only *Tetratheca* species present, seed capsules were evident.

Up to April 2002 there were three distinct flowering/seed-development/seed-release cycles over the ten-month period of this study with the third flowering continuing at that time. The flowering of plants at a location near Beresfield, about 30 kilometres further north, commenced about two weeks later than those at Wakefield, and this difference in time was maintained for all subsequent cycles. Flowering during early April 2002 was also observed in the Karuah Nature Reserve (S. Bell pers. com.).

The number of approaches to the *Tetratheca juncea* flowers by the bees was limited to no more than one visit in two hours by either species of bee to a patch of flowers. More often than not, an entire morning would pass without any bees being observed. All sightings were up until around the middle of the day and this is consistent with other studies where it has been shown that the time of maximum pollen availability is before midday (Goodwin 1986, King & Lengoc 1993) or that bee activity is in the morning (Bernhardt 1995, Larson & Barrett 1999). Buchmann (1983) notes that floral anthesis generally occurs around sunrise resulting in maximum pollen availability in the morning.

It is possible that in the absence of an observer, the bees could visit more frequently; there were a number of occasions when a bee would fly to a patch of flowers and then clearly notice the observer, fly erratically just in front of the observer for quite some time and then leave. Rayment (1935) describes this behaviour well, '… tedious, memorising flights, backward and forward, this way, that way, until one's patience is almost exhausted.' When the bee observes a change in the environment around the flowers that it has previously visited it goes through a process, 'memorising flight' to imprint that change into its memory.

The least obtrusive method of static observation was being seated about 2 metres from the flowers, although the method of randomly moving around a large area of plants proved more successful for finding bees. If they were approached after they had settled down to 'work' on a patch of flowers, the bees were found to be less prone to disturbance. On one occasion it was possible to get a few centimetres from a bee and watch it through a magnifier.

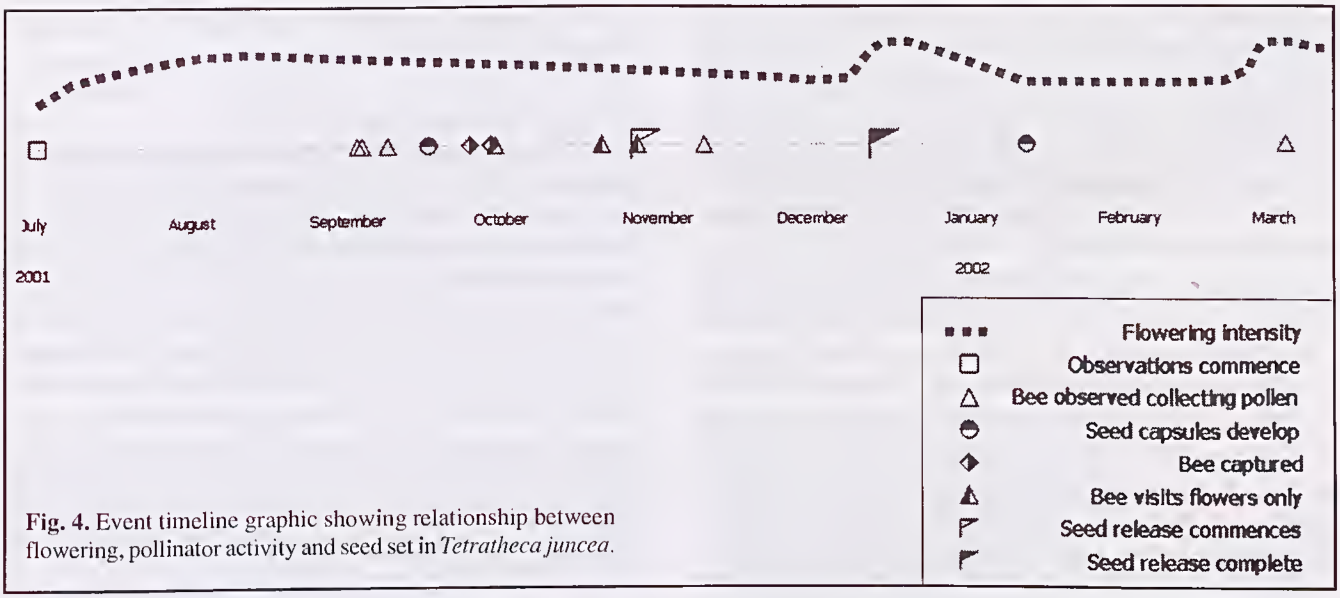

Fig. 4. Event timeline graphic showing relationship between flowering, pollinator activity and seed set in *Tetratheca juncea*.

The bees appeared to go through a process of assessment as to the suitability of the flowers for pollen removal, and several times were seen to make very brief inspections of two or three flowers in a group, and then leave. Buchmann and Cane (1989) have shown that *Bombus* bees make a similar quick assessment of the pollen return available from *Solanum* flowers. This process of assessment of potential reward should be expected and has been shown to occur in birds, for example the Glossy Black-Cockatoo (*Calyptorhynchus lathami*) that makes a quick assessment of the nutrient content of the seeds from the Forest Oak (*Allocasuarina* sp.) fruit before it expends further energy (Crowley & Garnett 2001).

Using the Anabat II detector it was possible to 'listen' for the buzz of the pollen extraction process, but the only opportunity came when a female *Lasioglossum convexum* was seen and landed first on a flower of *Comesperma* form *A* at Site 2. The bee burrowed into the central tube of the flower that is formed by a keel and lateral sepals, but made no detectable sound. This observation was probably of the bee collecting nectar since dissection of *Comesperma ericinum* flowers revealed them to be nectariferous. These flowers have a structure that suggests that pollination would be incidental to nectar harvesting by bees. The anthers open by broad apical slits and are positioned where pollen would fall on to the bee as it pushed into the tube for nectar. The stigma is flexed downward and would come into contact with the dorsal surace of the bee.

Following the visit to the *Comesperma*, the bee then landed on a flower of a nearby *Dianella caerulea* var. *assera* and immediately bursts of buzzing were recorded. Figure 5 shows a sound spectrograph of that recording. *Dianella* flowers have a solanoid structure and are known to require buzz-pollination (Bernhardt 1995).

The total duration of this event was 5.47 seconds with the longest burst being 0.58 seconds. This method of observation has potential in detecting the presence of a very tiny and fast moving bee and for accurately measuring the time elements of a flower visit. The Anabat II alters the sound structure and might not be informative about frequencies. Research into the application of this monitoring method is ongoing.

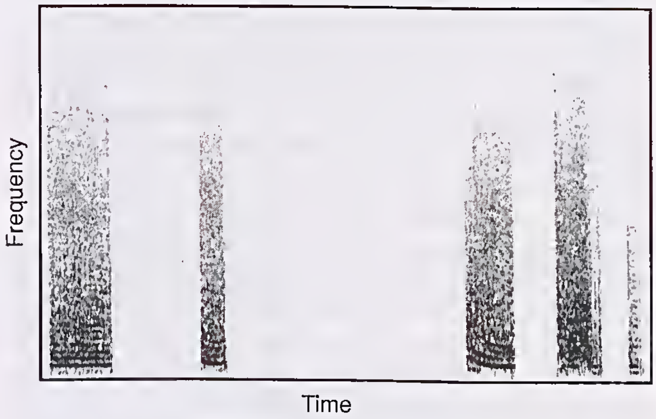

Fig. 5. Sound spectrograph of Anabat II detector recording of *Lasioglossum convexum* buzz-pollinating a *Dianella caerulea* flower. (Spectrograph created using Syrinx, Burt 2001)

Discussion

Tetratheca juncea pollination

The flowers of *Tetratheca juncea*, as with other members of the genus *Tetratheca* produce no nectar that could serve as a pollinator attractor, and it would appear that pollen is the sole reward available to an insect such as a bee. Payne (2000) observes that under ultra violet light there are apparent pathways evident in the petals of *Tetratheca juncea* that could serve as nectar guides for potential pollinators. It is beyond the scope of this study to determine the significance of this except to note that the presence of these areas *per se* does not necessarily mean that they are used by pollinating insects. A number of factors such as colour contrast, flower symmetry and the visual capability of an insect in ranges of frequency are involved in the function of nectar pathways (Penny 1983, Daphne & Kevan 1996). It may well be that these apparent nectar pathways are a part of a floral cue to the buzz pollinating bees in that the bees were all seen to land on the back of the flower before crawling between the petals to get to the pollen. The transient interest in the flowers that was shown by other insects may be a result of a misleading cue for nectar seeking insects.

The *Tetratheca* flower structure resembles what has been termed a *Solanum*-type (Vogel 1978), and later Solanoid (Faegri 1986), because of the dominance of these structural characteristics in *Solanum* (Solanaceae). Pollen extraction and thereby pollination of flowers with poricidal/porose anthers generally occurs through the process of buzz-pollination (also termed vibratory-pollination or sonication), achieved by bees grasping the androecium with the anthers against the venter and transferring vibrations through their body by means of rapid contraction of their indirect flight muscles (Buchmann 1983, Buchmann & Cane 1989, Harder & Barclay 1994). (Not by the buzzing of their wings as is often thought — the pollen extracted would be all blown away!). The audible component of the vibratory process is a useful detectable artefact to the energetics being applied to the flower parts by the bee in order to extract the pollen (Buchmann 1983). The poricidal anthers of *Tetratheca juncea* contain the pollen within locules in tapetal fluid. In common with other buzz-pollinated plants (King & Lengoc 1993, King & Buchmann 1996) the *Tetratheca juncea* anthers appear to dispense pollen, probably through the localised drying of the tapetal fluid. Dissection of a number of *Tetratheca juncea* anthers showed that at any time only a fraction of the total pollen content was dry, just inside the disseminating pore.

While it has been demonstrated that *Tetratheca juncea* is capable of self pollination (Bartier et al. 2001) the gynoecium architecture is not consistent with that of wind-pollinated flowers (Proctor et al. 1996) with the stigma surface being minute. Also the downward presentation of the flowers further limits the opportunities for air-borne pollen to land on the stigma surface. Bartier et al. (2001) determined that rates of autogamy were about 1 in 50 flowers in an undisturbed population and concluded that the majority of seed set found during their investigation would have been as a result of autogamy given the total absence of observed pollinators. This is not consistent with the observations in this study where the abundant flowers of both study sites produced no seed capsules for almost two months from July and that seed set occurred within two weeks of the first pollinator being observed (see timeline, Figure 4). Furthermore, in contrast to observations by Payne (2000) that seed capsule development and subsequent seed release only occur following the flowering period, during this study there was a concurrent process of flowering, seed capsule development and seed release that followed the appearance of the first pollinators and this continued into 2002 until bees were no longer active in colder weather. A low level of flowering continued through the colder months (with some flowers present for each of the 12 months) with no seed capsule development and this was taken as an indication that the bees were no longer active.

Conservation importance of pollinators

For some plants, pollinators are readily available and these can simply be the wind or a wide variety of both invertebrate and vertebrate fauna. For other plants pollination is a specialised process with limited pollinators available or with limited pollinating opportunities being made available by the plant. Without a pollinator most plant species, even those able to vegetatively propagate, would become extinct and a decline in pollinators has broad implications for biodiversity (Allen-Wardell et al. 1998, Kremin & Rickets 2000).

Members of the two genera of bee observed collecting pollen from *Tetratheca juncea* in this study, *Lasioglossum (Chilalictus)* sp. and *Exoneura* sp., have been recorded collecting pollen from a number of other plant species throughout Australia such as *Dianella caerulea* var. *assera*, specifically by *Lasioglossum convexum* (Bernhardt 1995) and *Acacia* sp., (Bernhardt 1987). In southern Tasmania, bees of the *Lasioglossum* genus (*Austrevylaeus* and *Chilalictus*) were recorded at nectarless plants of *Dianella*, *Acacia*, *Hibbertia*, *Tetratheca* (*glandulosa*) and nectarifierous plants of Fabaceae, Epacridaceae and Myrtaceae (Hingston 1999). During the current study, plant species other than *Tetratheca juncea* from which *Lasioglossum convexum* was observed collecting pollen or nectar were *Comesperma ericinum* form *A* (Polygalaceae), *Dianella caerulea* var. *assera* (Phormiaceae), *Dillwynia retorta* (Faboideae), *Hibbertia serpyllifolia* (Dilleniaceae), and *Persoonia levis* (Proteaceae). *Exoneura* sp. was seen collecting pollen from *Tetratheca juncea* at a Beresfield population about 30 kilometres north of the two study sites but was not seen collecting from other species. Bernhardt (1987) notes that bees which collect from nectarless flowers are generally members of polylectic genera (i.e. they collect pollen and nectar from a number of plant genera across several families).

Both bee species are loosely social with different ecology. *Lasioglossum convexum* nests in tunnels in the ground with side brood chambers; an environmental requirement would be suitably textured soil that the bee can tunnel into. *Exoneura* sp., often referred to as 'reed bees', nest in hollow stems and rely on either the centre of a deteriorating dead stem such as in fern stems or *Lantana*, or hollows formed by the larvae of wood-boring beetles (Rayment 1935, Michener 2000). Bees of both genera remain dormant for winter and emerge as the weather warms (Dollin et al. 2000) though this has not been specifically demonstrated for *Lasioglossum convexum*.

The pattern of bee visitation as observed directly, and as inferred by the distribution of seed set among the plants, has implications for the genetic diversity of the plant populations. The bees exhibited flower constancy (Goulson 1994) over the short period that the flowers were visited and it became apparent that only small patches (generally much less than 1 m^2) were being pollinated. Given that, as a consequence of rhizomal spread (Payne 2000, Driscoll & Bell unpub.) the plants in that small area would most likely all be ramets from the same genetic source, pollination was of the kind that has been described as 'zoophilous autogamy' (Bernhardt 1976). The possibility also exists for facilitated self pollination where pollen being extracted attaches to the stigma of the same flower (Larson & Barrett 1999). In one instance at site 1, a single plant with five stems developed 15 seed capsules from 20 flowers in a location that was surrounded by other plants in plentiful flower but with few to no seed capsules. During January 2002, a group of plants in about 1 m^2 that had not produced any seed capsules since July 2001 developed a number of seed capsules. This conclusion is consistent with early work reviewed by Levin (1978) showing that pollinator foraging, based on the efficient use of distance and time, will have an effect on the genetic composition within and between plant populations. Considerable investigation into the genetic structure within these populations will be needed before the proportion of autogamy to outcrossing in *Tetratheca juncea* can be determined with confidence.

The very low seed set reported in *Tetratheca juncea* populations (Payne 2000, Bartier et al. 2001) is a likely indication of a pollinator-limited reproductive system. The concept of pollinator-limitation is built around the premise that seed set in a flowering plant population is below a level that would be achieved were more pollinators available (Calvo & Horvitz 1990). Bartier et al. (2001)'s work on hand pollination provides supporting evidence for *Tetratheca juncea* being pollinator-limited with fruit-set percentages being significantly higher in hand pollinated flowers than in unmanipulated flowers. The combination of pollinator limitation and fragmented and disjunct populations of *Tetratheca juncea* has implications for the future prospects of the plant. Agren (1996) demonstrated that for a pollinator limited species, there was a positive correlation between population size and seed production indicating inadequate pollen transfer in small populations. Bartier et al. (2001) found for *Tetratheca juncea*, that there was a positive correlation between fruit production and population size as measured by plant biomass. The question arises as to whether the pollinators of *Tetratheca juncea* have always been a limiting factor in the reproductive process of the plant or whether there has been a decline in pollinator numbers over time.

The two bee species collecting pollen from *Tetratheca juncea* are polylectic and so it would appear that the bees are less dependant on *Tetratheca juncea* than it is on the bees. This might provide a lead as to why *Tetratheca juncea* has such a long and profuse flowering with continued spasmodic flowering throughout a year and could also suggest that the reproductive process has always been pollinator-limited.

If it is the case that the flowering pattern of *Tetratheca juncea* is an adaptation to a pollinator-limited breeding system then knowledge of the ecology of pollinators in the ecosystem is of significance in relation to the long-term viability of the species. Hingston (1999) has shown an affinity between plants and their bee pollinators in Tasmania in such a way that a variety of species and genera with overlapping flowering periods encourage bee activity, and that nectariferous plants flowering in the same area as nectarless plants facilitates pollinator visits to the latter. In an earlier study, again in Tasmania, Hingston (1998) showed that the composition of native bee fauna varied within vegetative communities throughout the year. It is possible that habitat degradation through various anthropogenic activities, and maybe in particular frequent fire, has resulted in a simplification of floristic composition and vegetative structure that has led to a decline in pollinator numbers.

Conclusion

Findings from this study with respect to the pollination ecology of *Tetratheca juncea* are:

- There is a strong flowering period from September to January, though a number of flowers can be found on some plants across the geographic range of the plant in all months of the year;
- Two species of native bee *Lasioglossum convexum* and *Exoneura* sp, were confirmed collecting pollen from the flowers by way of buzz-pollination;
- Fruiting only occurred in coincidence with flower pollination by these bees;
- Flowering, seed set and seed release was a concurrent process while ever the bees were active;
- The bees are polylectic and the sexual reproductive process in *Tetratheca juncea* appears to be pollinator-limited.

This study, along with the work of others (Bartier et al. 2001), has shown that refreshment of the genetic content within populations and between very disjunct populations is poor. It could well be that the current populations of *Tetratheca juncea* are long established, predominantly clonal colonies each containing little genetic variation and with local adaptive genotype differences between the disjunct occurrences of the plant. If this were the case and pollinator numbers have significantly declined there could be a loss of mutualism between the bees and their floristic habitat and *Tetratheca juncea*, being nectarless and a pollen source of last resort, could be undergoing a process of insidious delayed extinction (Johnson & Steiner 2000). It would be presumptuous to decide that this was not a possibility and further research is needed into the dynamics of the ecology of this rare plant and its pollinators.

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Pollination of the wet forest herb *Pollia crispata* (Commelinaceae)

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Abstract: The flower structure of *Pollia crispata* (R.Br.) Benth. allows access by a taxonomically diverse assemblage of pollinating insects. Patterns of flower anthesis, and removal of pollen, suggest adaptation to diurnal flower visitors. Flowers are pollinated by insects, but *Pollia crispata* can produce viable seeds independent of insect pollination, and plants can reproduce and spread vegetatively subsequent to founding events. The composition of the pollinator fauna is dominated by syrphid flies, halictid bees and the apid bee *Trigona carbonaria*, but most insect visitors observed have broader recorded flower host ranges. In general, the insects recorded from *Pollia crispata* flowers are restricted to the understorey and ground strata of regional subtropical rainforests.

***Cunninghamia* (2003) 8(1): 141–146**

Introduction

In Australia, herbs in the genus *Pollia* (family Commelinaceae) comprise two endemic species, *Pollia crispata* (R.Br.) Benth. and *Pollia macrophylla* (R.Br.) Benth. (Harden 1993). *Pollia crispata* occurs in New South Wales and Queensland, *Pollia macrophylla* is restricted to Queensland (Hnatiuk 1990).

Pollia crispata (Figures 1, 2) is found along creeklines in montane and subcoastal rainforest and wet sclerophyll forest, and can form dense spreading mats on sunlit creek margins, drainage lines and associated slopes where soil moisture levels are high. These habitats are vulnerable to invasion by exotic weeds, such as the related South American weed *Tradescantia fluminensis*. Like most flowering plants of the subtropical rainforest understorey in Australia, no information is available on flower visitors, or reproductive ecology of *Pollia crispata*. Despite the species frequently occurring in dense populations very few, if any, visitors to flowers are normally observed by casual observation. The principal aim of this study was to identify flower visitors and potential pollinators.

Methods

The study was largely confined to a single patch of *Pollia crispata* plants growing along a shallow drainage line in regenerating mixed wet sclerophyll forest and subtropical rainforest at Lorien Wildlife Refuge (31°45'00''S, 152°32'30"E, approximately 100 m a.s.l.), north of Taree on the New South Wales north coast. This patch constituted the largest known population at the location. The two intergrading forest communities had been logged, or structurally damaged as a result of logging, in the late 1970s.

Observations of plants and flower visitors were undertaken (collectively over 34 days) during 1996, and from 1998 until January 2003. These extended from mid November until late

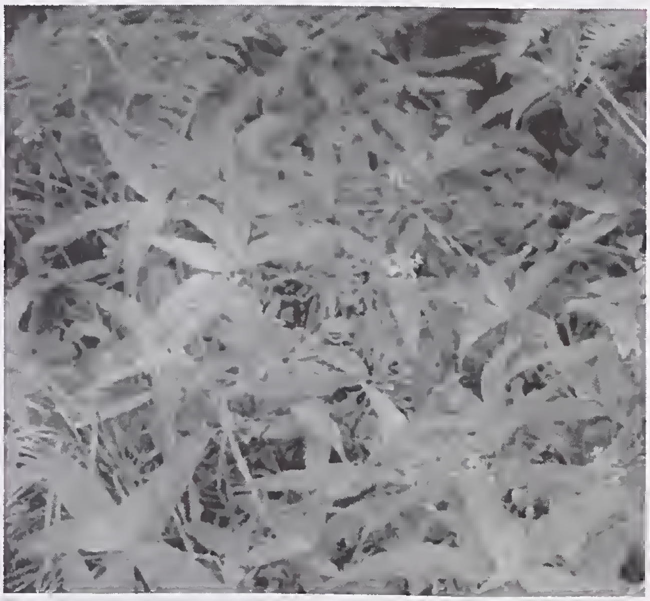

Fig. 2. *Pollia crispata* clump in wet sclerophyll forest, Lorien Wildlife Refuge

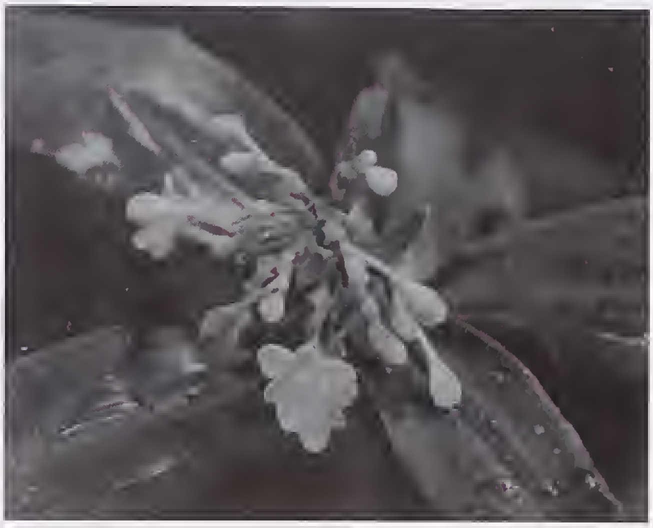

Fig. 1. *Pollia crispata* flowers

February (the general period of flowering), and comprised 1–3 hours each day of observation. The timing of individual daily observations commenced as early as 0830 hours and as late as 1940 hours (dusk). Throughout each day flowers received intermittent and dappled sunlight and were frequently fully shaded. Most insects visited between early daylight and midday (> 0800–1200 hours), and observations in 1999–2003 were generally restricted to this period. Daily weather conditions were usually hot, to very hot and humid. The 2001–2002 season of observation coincided with pronounced drought conditions, and drought conditions preceded the 2002–2003 season of flowering.

In addition to the Lorien site, flowering plants were briefly observed in montane warm temperate rainforest at Coombadjha Creek (approximately 1000 m a.s.l.), Washpool National Park northwest of Grafton, in 1997, and in subtropical rainforest at Gumbaynggir Nature Reserve (previously League Scrub Flora Reserve) (> 900 m a.s.l.) near Bowraville in 1998 and 2001.

Flower structure and pollen were examined using a light microscope. To determine if *Pollia crispata* is dependent on pollinators for pollen transfer, a total of thirty-two unopen flowers, distributed between three plants, were covered with fine nylon bags to exclude pollinators. The flowers were enclosed on the 27 December 1998, and the bags later removed on 8 March 1999, by which time flowering of the population had ceased.

The behaviour of all insects on flowers was observed. Voucher specimens of all insect species visiting flowers were collected, using a small hand-held net, for identification and examination of pollen loads (Table 1). Pollen from individual insects was compared with voucher pollen collected from *Pollia crispata*. Voucher insect specimens are deposited in the Australian Museum (Sydney), Museum Victoria (Melbourne) and the Lorien Wildlife Refuge field research collection. Undescribed halictid bees, collected during the study, have been deposited in Museum Victoria. Australian plant names follow Harden (1990–93).

Results

Pollia crispata is a perennial, annually flowering herb and individual plants grow vegetatively from adventitious stem roots. In 1996 the *Pollia crispata* clump at Lorien Wildlife Refuge covered an area approximately 3 × 5 m and available flowers comprised more than 100 inflorescences. By November 2000 the population had expanded vegetatively to an area approximately > 10 m × 5 m. However, plants (in dense shade) close to regenerating wet sclerophyll forest and rainforest had died back, or 'opened-up' (i.e. foliage no longer formed a closed mat), exposing bare ground. These heavily shaded plants were much lower than those growing in sunlit conditions (average < 0.33 m, as opposed to > 0.75 m in height). By late 2001 some grass, ferns and additional herb species (e.g. *Lobelia, Pratia*) had begun to colonise open ground space previously covered by the dense *Pollia* mat, and by January 2003 ferns had largely replaced the original *Pollia* population and *Pollia* had colonised adjacent open areas.

The flowers of *Pollia crispata* are actinomorphic, bisexual, approximately 8–9 mm wide, in terminal inflorescences; petals 3 coloured white, sepals 3 coloured greenish-white; gynoecium superior, style long and narrow; stamens 3; with 2–3 long staminodes or non-functional stamens. Flowers do not appear to produce nectar and there are no obvious nectar guides (and nectar guides and patterns were not apparent under ultra violet light). Flowers open sequentially each morning and appear slightly protogynous. The perianth is open and shallow and does not restrict access. However, each petal can act as a landing platform, if orientated downwards, in which case the lower petal is 'pseudolobellate'. Pollen is bright yellow, dry and easily displaced from anthers; pollen exine pattern is reticulate. The bright-coloured pollen appears to convey the main visual recruitment signal.

Bagged flowers set seed but actual numbers were not counted as the presentation of the hard nut-like seeds made it difficult to assign them to individual flowers. Twenty seeds collected from bagged flowers were sown in pots; 5 seeds germinated and grew to mature plants, and these had flowered by January 2003. The formation of viable seeds indicates that *Pollia crispata* is not dependent upon insect pollinators for fertilisation to occur.

By mid-January 2002 local drought conditions at the Lorien site were severe, and although plants possessed numerous flower buds none were open. Flower buds were progressively aborted such that none were available later in the flowering season to flower-visiting insects.

Insects were not observed to visit flowers during the night or during rain. All flower visitors were able to contact the stigma and stamens and are considered potential pollinators.

Pollen from daily-opening flowers had normally been removed by insects by 1300 hours. In general, abundance of insects decreased when flowers were in full sun and insects were absent in late afternoon and at dusk. The majority of insect species observed visited shaded flowers, and flowers in dappled sunlight, even when flowers were hidden by low overhanging ferns. Many species were not observed visiting flowers in full sunlight. Exceptions were several species of *Syrphini* (Diptera: Syrphidae) (*Melangyna damastor* [Walker], *Syrphini* species 1, 2, *Betasyrphus* sp.) which preferred sunlit flowers. The syrphid *Episyrphus* sp. was common most seasons but generally restricted its visits to shaded and dapple-lit flowers. Most halictid bees were very timid and easily disturbed. On one occasion (13 December 2001) the large trap-lining anthophorine bee *Amegilla bombiformis* (Smith) approached flowers at the Lorien site but did not land.

Table 1. Biotic pollen vectors, showing number of individuals, dates observed and main sites of pollen lodgement, visiting *Pollia crispata* flowers, Lorien Wildlife Refuge

Dates observed = dates when taxa were observed on flowers; no. individuals = number of specimens examined for pollen; n/a = no apparent pollen; 'home' pollen = approximate percentage of *Pollia* pollen on number of individuals examined for pollen; number of additional foreign pollen species in brackets; letters assigned to undescribed *Lasioglossum* spp. are K. Walker interim identification codes.

Taxa	No. individuals	% home pollen	Dates observed	Main sites of pollen lodgement
DIPTERA				
Bombyliidae				
Geron nigrocciput Evenhuis	2	n/a	27.12.98, 30.11.01, 4.12.01, 18.12.01, 9.1.03	
Syrphidae: Syrphini				
Betasyrphus sp.	1	100	16.12.99, 3.2.00	face, pro–, meso– and hind femora, ventrites generally, lateral margins of basal metasomal segments, but particularly sternopleura and mesopleura
Episyrphus sp./spp.	5	>99-100	15.11.96, 17.11.96, 26.12.98, 28.12.98, 31.12.98, 3.1.99, 11.12.99, 19.1.00, 3.2.00, 4.2.00, 25.2.00, 30.11.01, 8.1.03	ventral areas, thorax, fore, mid and hind legs, inner ocular margins (comb-like long setae on mid femora)
Melanogyna damastor (Walker)	1	100	15.11.96, 29.11.96. 26.12.98, 24.11.99, 9.12.99. 5.12.0, 13.12.01	thorax and forelegs generally
Syrphini sp. 1	2	100	26.12.98, 29.12.98, 31.12.98, 11.12.99, 19.1.00, 30.11.01	scattered grains on whole body surface and face, but particularly ventrites, sternopleural and pteropleural regions
Syrphini sp. 2	1	100	31.12.99	scattered occasional grains on hind femora, anepisternites, sternopleural and pteropleural regions
Syrphini sp. 3	1	~50 (2)	30.11.01	notopleuron, isolated grains on body generally
HYMENOPTERA				
Apidae				
Amegilla ?pulchra (Smith)	1	>50	26.12.98, 18.12.00, 4.12.01	hind tibiae and femora
Apis mellifera Linnaeus	4	100	4.2.00, 23.11.00, 3.12.00, 18.12.00, 23.12.00, 30.11.01, 4.12.01, 13.12.01, 18.12.01, 16.1.03	corbiculae — hind leg, scattered grains elsewhere
Exoneura sp.	0		8.1.03	
Trigona carbonaria Smith	2	100	15.11.96, 2.12.96, 3.12.96, 27.12.98, 23.11.00, 3.12.00, 18.12.00, 23.12.00, 30.11.01, 4.12.01, 13.12.01, 18.12.01, 8.1.03, 9.1.03, 16.1.03	corbiculae — hind leg, scattered grains elsewhere
Colletidae-Hylacinae				
Amphylaeus nubilosellus (Cockerell)	1	100	9.12.99	scattered few grains on body and wings generally
Hemirhiza melliceps Cockerell	3	100	29.12.98, 3.1.99, 11.12.99	few (or no) grains scattered on body surface generally, or few grains restricted to meso– or metasoma
Halictidae				
Lasioglossum (*Austrevylaeus*) sp. nov. 'J'	1	100	4.1.99, 9.12.99, 3.2.00	ventral surface and legs generally, particularly hind femora and basal ventrites, propodeum and mesasomal metapleuron
Lasioglossum (*Austrevylaeus*) sp. nov. 'L'	6	100	2.12.96, 3.12.96, 27.12.98, 29.12.98, 31.12.98, 3.1.99, 13.12.99, 19.12.99, 19.1.00, 4.12.01, 8.1.03	hind femora, tibiae and tarsomeres, ventral scopae of metasoma, lateral basal margin of mesosoma
Lasioglossum (*Austrevylaeus*) sp. nov. 'Y'	2	~60–100 (2)	9.12.99, 3.2.00	ventral surface and legs generally, particularly hind femora and ventrites 1–3
Lasioglossum (*Callalictus*) *tooloomense* (Cockerell)	1	100	9.12.99	ventral surface and hind legs generally, especially hind femora
Lasioglossum (*Chilalictus*) *convexum* (Cockerell)	1	<50 (2, ?3)	5.12.01, 8.1.03	base of propodeum, metapleura, base of metasoma and mid legs, but particularly hind legs
Lasioglossum (*Chilalictus*) *polygoni* (Cockerell)	5	<40–100 (2, ?3)	29.12.98, 9.12.99, 16.12.99, 3.2.00, 18.12.00, 8.1.03	ventral surface generally, but particularly propodeum, hind legs and ventrites 1–2
Lasioglossum (*Parasphecodes*) *atronitens* (Cockerell)	4	>99–100 (1, ?2)	29.12.98, 31.12.98, 30.11.01, 4.12.01, 16.1.03	hind femora, tibiae and tarsomeres, ventral surface of metasoma, base of propodeum, scattered grains on body surface generally
Lasioglossum (*Parasphecodes*) *leichardti* (Cockerell)	2	>99–>90 (2)	3.2.00, 30.11.01, 5.12.01, 8.1.03	base of propodeum, ventral surface generally, but particularly hind legs and basal half of metasoma
Lasioglossum (*Parasphecodes*) *musicum* (Cockerell)	5	>95–100 (2)	26.12.98, 29.12.98, 3.1.99, 19.12.99, 18.12.00, 23.12.00, 30.11.01, 5.12.01	petiole, propodeum and mesosomal metapleura, basal segment of metasoma, ventral surface generally, hind trochanter, femora, tibiae and tarsomeres
Lasioglossum sp.	1	100	3.1.99	hind tibiae and tarsomeres, ventral scopae of metasoma
Nomia aurantifer Cockerell	1	100	19.12.99, 18.12.00, 13.12.01, 8.1.03	scattered grains over whole body, but especially ventral surface generally, apex of metasoma, hind tibiae and hind femora
Formicidae				
Myrmecia nigrocincta Smith	0		30.11.01, 4.12.01, 9.1.03	
Myrmecia ?tarsata Smith	0		23.11.00, 3.12.00, 30.11.01, 4.12.01, 9.1.03	
REPTILIA				
Scincidae				
Saproscincus ?galli Wells and Wellington	0		3.1.99	

There was annual and daily variation in the number of insect taxa visiting flowers (see Table 1). No insects were recorded on some days. Greater numbers of taxa were observed visiting flowers at the Lorien site during the summer of 1998–1999 and 2000–2001, although approximately equal time was spent each year (until January 2002) observing flowers (Table 1). Only four taxa were observed in 1996 and this relatively low diversity may be related to the smaller patch size of the *Pollia* population at that time, because numbers of available flowers/inflorescences can influence visitation. In most years *Episyrphus* sp. and *Lasioglossum* sp. nov. 'L' were the most commonly observed flower visitors. For example, *Lasioglossum* sp. nov. 'L' comprised 48 % and *Episyrphus* sp. comprised 32 % of visits to *Pollia crispata* flowers during 1 hour of morning observations (on the 3 January 1999) out of twenty-five visits by 6 insect taxa. However, both species were rarely seen in 2001–2002.

No insects were observed visiting flowers at Washpool National Park during brief daytime inspections. Three species of syrphid fly (*Melangyna damastor*, *Syrphini* sp. 2, *Betasyrphus* sp.), and the bees *Trigona carbonaria* Smith and *Lasioglossum musicum* (Cockerell) were observed on *Pollia crispata* flowers at Gumbaynggir Nature Reserve. These species were also recorded from Lorien Wildlife Refuge. At Lorien Wildlife Refuge, in 1998–1999, visits by *Trigona carbonaria* occurred when most of the *Pollia crispata* population was in flower but *Trigona* was not observed when flower numbers diminished later in the flowering season.

Pollen loads are in part related to the amount of time spent foraging, but except for the bombyliid fly *Geron nigroccipnt* Evenhuis all bees and flies examined carried *Pollia crispata* pollen (Table 1). The 2 hylaeine bees (*Amphylaeus nubilosellus* [Cockerell], *Hemirhiza melliceps* Cockerell), however, only carried occasional scattered pollen grains. The syrphids appear to be pollen feeders, and except for the long-tongued bee *Amegilla ?pulchra* (Smith) and *Geron nigroccipnt*, other visitors were relatively short-tongued insects whose visits to *Pollia* flowers are unimpeded owing to the shallow open structure of the perianth. *Amegilla ?pulchra* foraged rapidly, was easily disturbed, and moved quickly between individual flower clusters. The introduced honey bee *Apis mellifera* Linnaeus was observed visiting *Pollia crispata* flowers only in the 2000–2001 and 2001–2002 seasons. In an attempt to remove pollen *Apis* occasionally agitated flowers by shaking, but did not 'buzz' flowers. On the 4 December 2001 a single *Lasioglossum musicum* attempted briefly to 'buzz' flowers. Beetles, which regionally are a common element of entomophilous subtropical rainforest trees (Williams 1995), were not observed on *Pollia* flowers.

Of particular interest were observations on the 3 January 1999 of a small skink, *Saproscincus ?galli* Wells and Wellington. The skink climbed with agility over and between *Pollia* plants using its tail to grasp stems, and on one occasion leaping > 25 cm from leaf to branch. The skink frequently contacted flowers but no attempt was made to isolate pollen from its body.

Three new *Lasioglossum* bee species, in the subgenus *Austrevylaeus*, were collected during this study. One of these, *Lasioglossum* sp. nov. 'L', is a distinctive black species with golden yellow setae on the thorax. However, to date only females have been collected and males remain unknown at the site. During observations *Lasioglossum* sp. nov. 'L' restricted its foraging to *Pollia crispata* and did not visit adjoining co-flowering *Lobelia* sp. (Campanulaceae). Pollen loads on the 6 individuals examined consisted of 'home' pollen only. This species preferred very shaded flowers but otherwise exhibited no obvious foraging pattern. Generally no more than 4 *Lasioglossum* sp. nov. 'L' bees were observed at any one time at the *Pollia* clump. Individuals would spend up to approximately three minutes collecting pollen from individual flowers and used fore and mid-legs to pack pollen into hind-leg scopae and setae on the abdominal ventrites.

Discussion

World wide the Commelinaceae comprise 42 genera and approximately 620 species, mainly distributed in the Tropics (Harden 1993). With the exception of brief observations on *Commelina cyanea* (Williams 1993) flower visitors and pollinators of the Australian Commelinaceae flora are unrecorded.

The daily patterns of flower opening and removal of pollen by insects indicates adaptation to diurnal visitors by *Pollia crispata*. Although flowers are allophilic, offering unrestricted access to a taxonomically broad range of invertebrate flower visitors, the pollinator fauna of *Pollia crispata* is apparently dominated by syrphid flies, halictid bees, and *Trigona carbonaria*. However, Kato (2000) has recorded small *Lasioglossum* bees, and the beetle genera *Protaetia* (Scarabaeidae) and *Chlorophorus* (Cerambycidae), visiting white-flowered, actinomorphic, *Pollia japonica* in the Ryukyu Archipelago, Japan. Halictid and syrphid-dominated plant-pollinator relationships are also recorded for Australian ground orchids in the genus *Thelymitra*, and the ground stratum more generally (Dafni & Calder 1987). *Trigona carbonaria* is recorded from numerous flowering subtropical rainforest plants in the study region and elsewhere (Williams 1995, Williams & Adam 1997, G. Williams unpubl. data).

The related herb *Commelina cyanea* is also visited and pollinated by bees and syrphid flies. Williams (1993) records native halictid, colletid and trap-lining anthophorine bees (e.g. *Amegilla ?pulchra*, *Nomia aurantifer* [Cockerell]), and the syrphid fly *Syritta* sp. as pollinators. Contrary to the actinomorphic open and white flowers of *Pollia crispata*, flowers of *Commelina cyanea* are bright blue and slightly zygomorphic suggesting that flower shape and colour may be poor indicators of pollinator taxa. This is supported by the observations of Kato and Miura (1996) who recorded syrphid flies as the pollinators of blue-flowered, actinomorphic, *Commelina communis* and pink-flowered, zygomorphic, *Murdannia keisak* (Commelinaceae) in a Japanese lowland marsh community. Hingston and McQuillan (2000), investigating plant-flower visitor associations in a range of

Tasmanian vegetation formations, found that flower pollination syndromes may be unreliable predictors of pollinators. Rather, occupation of a particular vegetation stratum may be a better predictor of pollinator association in wet forest types.

A number of the flower visitors recorded during this study have broader wet forest host plant associations in the Taree region. At Lorien Wildlife Refuge *Episyrphus* sp., was occasionally observed on adjacent *Aneilema acuminatum* (Commelinaceae) herbs (this is an endemic genus restricted to the Northern Territory, Queensland and New South Wales [Harden 1993]) (G. Williams unpubl. data). *Syrphini* sp. 1 was observed on male flowers of *Clematis glycinoides* (Ranunculaceae). In addition to *Commelina cyanea, Nomia aurantifer* is recorded from the flowers of the small mangrove tree *Aegiceras corniculatum* (Myrsinaceae) and the mass-flowering canopy vine *Austrosteenisia blackii* (Fabaceae) (Williams 1993). *Lasioglossum musicum* occasionally visited *Rubus rosifolius* (Rosaceae) shrubs on rainforest margins, *Lasioglossum atronitens* (Cockerell) was also collected from *Dianella caerulea* (Liliaceae) and the scrambling vine *Hibbertia scandens* (Dilleniaceae), and *Lasioglossum tooloomense* (Cockerell) was also a rare visitor to *Dianella caerulea* (G. Williams unpubl. data). *Lasioglossum polygoni* (Cockerell) is recorded from the shrub *Senna acclinis* (Caesalpinioideae) (Williams 1998) and the subcanopy tree *Diospyros australis* (Ebenaceae) (Williams & Adam 1997). *Amphylaeus nubilosellus* and *Hemirhiza melliceps* have been regionally recorded from a number of rainforest canopy and understorey trees and shrubs (Williams 1998, Williams & Adam 1997). At Gumbaynggir Nature Reserve *Lasioglossum musicum* was also collected buzz-pollinating adjacent flowering *Senna* × *floribunda* (Caesalpinioideae), a native of Mexico, that now occurs throughout coastal New South Wales. *Melanogyna damastor* is encountered in sunlight wet forest margins on the New South Wales north coast on numerous low-flowering plants (G. Williams unpubl. data). The native bees *Amegilla ?pulchra, Amphylaeus nubilosellus, Hemirhiza melliceps, Lasioglossum atronitens, Lasioglossum convexum* (Cockerell), *Lasioglossum leichardti* (Cockerell), *Lasioglossum musicum, Lasioglossum polygoni* and *Trigona carbonaria*, however, have ecological and floral host ranges not limited to wet forest types (Cardale 1993, Walker 1995).

With the exception of *Amphylaeus nubilosellus*, the insects visiting *Pollia crispata* flowers appear to be restricted to understorey strata (including open forest floor areas) in the study region. Many taxa visiting *Pollia crispata* could best be described as cryptic visitors as these preferred shaded or dapple-lit flowers and individual foraging events were commonly inconspicuous. Williams and Adam (1997) indicated that *Hemirhiza melliceps* foraged preferentially at shaded flowers of the rainforest understorey and observations during this study confirm this. Notable exceptions, during the study, to apparent cryptic foraging behaviour were a number of *Syrphini* and *Amegilla ?pulchra*.

Pollination of *Pollia crispata* (and potentially that of the additional Commelinaceae mentioned here, *Commelina cyanea* and *Aneilema acuminatum*) differs from the entomophilous pollination strategy of mass-flowering subtropical rainforest canopy trees. In the latter, pollination is primarily achieved by a diverse assemblage of ecologically generalist Diptera, Coleoptera and Hymenoptera (Williams 1995, Williams & Adam 2001), within which Syrphidae (and especially *Syrphini*) and native Apoidea are only a small or inconsequential proportion (Williams 1995, Williams & Adam 1997). The pollinator relationships found in *Pollia crispata* are more typical of those documented in the rainforest understorey, where plant-pollinator mutualisms are generally more specialised and pollinator assemblages on individual plants are less diverse (e.g. Hamilton 1897, Williams & Adam 1994, 1999, Williams et al. 2001), and groups such as bees are more prominent (e.g. Gross 1993, Williams 1998). Rainforest understorey communities, however, are vulnerable to piecemeal clearing for recreational facilities, paths and roads, and to blanket invasion by exotic weeds such as *Tradescantia fluminensis* and Asparagaceae (Williams & Adam 1999, Williams & Gerrand 1998).

However, *Pollia crispata* is not totally dependent on pollinators. Individual plants are able to self-pollinate, and founding populations can expand by root growth from stolons; as was the case in the principal study population at Lorien Wildlife Refuge. Restrictions to colonisation appear to be absence of moist areas and dense shading.

Two of the seasonally most abundant pollinators observed during this study, *Episyrphus* sp. and *Lasioglossum* sp. nov. 'L', have restricted ecological ranges and were not collected by Williams (1995) during the extensive sampling of mass-flowering rainforest canopy trees in the region. *Lasioglossum* sp. nov. 'L' is presently known only from Lorien Wildlife Refuge and is currently known only from *Pollia crispata*. These apparently restricted vertical ranges and plant associations, within wet forest strata, suggest that the loss of relatively common or localised native understorey plants, and clearing of the entire understorey stratum, may have important impacts on pollinator faunas, with individual species being susceptible to local extinction.

Volant insects can exhibit limited ability to enter, and cross, cleared landscape matrices (see Campbell & Brown 1994). Consequently, pollinators with restricted host associations may be unable to recolonise isolated vegetation remnants even if suitable host plants are reintroduced. Loss of pollinators, and subsequent breakdown in plant-pollinator relationships may have important flow-on impacts on the maintenance of floristic and overall biological diversity in reserves.

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Shared exotica: Plant invasions of Japan and south eastern Australia

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Abstract: Japan and south eastern Australia have a large exotic flora in common, in spite of contrasting histories, physiographies and land-use patterns. There are some 187 common invading species and at least 71 of these are widespread in both locations. Some 15 widespread exotic invaders in Japan have not been recorded in Australia and a number of native Japanese plants that could be introduced as ornamentals and escape cultivation are noted. The incursion of most exotic species to Japan has been historically recent. The lack of quarantine for plants (apart from parasitic plants and plants infected with disease) coupled with large importations of wheat and soybeans from north America and contaminated grain and fodder for farm animals has led to an exponential rate of plant invasion in Japan. The apparent lack of impact of woody invading species in Japanese forests and forests margins may be due simply to the relatively short time invading species (some with long juvenile periods) have been naturalised.

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Introduction

In spite of vastly different histories of human occupation and land use, Japan and south eastern Australia host many of the same exotic plant species. Michael (2001) noted over a score of taxa in the family Asteraceae common to eastern Asia and eastern Australia and mentioned that many other plants from other plant families could be included. In this paper we compare the invasive floras of Japan and south eastern Australia.

Southern Australia and Japan are spread over similar latitudes in different hemispheres and the range of climates on the east coast of Australia are similar to those in Japan, from warm temperate to cool temperate, although rainfall is more summer-dominant at mid-latitudes (around 35°) and winters are colder in Japan especially at high-latitude (Michael 2001). Inland from the coast in eastern Australia, immediately west of the Great Dividing Range, the climate becomes drier than Japan and increases in aridity to the west. For the purposes of this paper south eastern Australia is defined as south of latitude 25° and east of longitude 141° and includes Tasmania.

Japan is 70% mountainous and its physiography is a much more complex mosaic than eastern Australia which has larger contiguous areas of similar altitude. As a consequence of this, patterns of land use are quite different in each country including the types of agriculture practised.

Prior to 1788, Australia had been occupied for at least 60 000 years by the Koori people who were principally, semi-nomadic hunter-gatherers, relying on indigenous plants and animals. Most of the eastern area of Australia was covered with evergreen forests and woodlands. With European settlement came forest clearing, European agricultural practices and the plants of European agriculture as well as familiar ornamental plants and herbs. There was a huge influx of exotic plants into Australia in the 19th and early 20th centuries. Agricultural enterprises have been principally sheep and cattle grazing and dry-land wheat farming, although a greater range of agricultural and horticultural activities has been taking place in the last 30 years.

In Japan, agriculture has been practised for more than 2 500 years (Maekawa 1943, Kasahara 1976). Paddy rice was introduced at the end of the Jomon period (circa 300 B.C.) but upland farming with *Echinochloa*, *Setaria*, *Fagopyrum* and tropical *Japonica* upland rice was conducted even earlier. Although there was a period of contact with Europe in the 16th century, Japan had remained generally isolated by *sakoku* (national seclusion) from external influences, apart from neighbouring Korea and China, until 1853, the end of the Edo period just before the Meiji revolution in 1868. So it was after this date that the majority of exotic plants have been introduced to Japan. From 1910 to 1945 Korea was a Japanese colony and migration flows built up to a total of about 2 million Koreans in Japan in 1945; Chinese also migrated in smaller numbers at this time.

In view of these contrasting histories and agricultural practices, it is remarkable that so many invading plants are common to both Japan and Australia. Understanding the reasons for this and why some exotic plants are exclusive to one country may contribute to the development of invasion theory.

Early invasions

Based on archaeological evidence in Japan a limited number of exotic species that are also exotic invaders in eastern Australia are thought to have arrived during the Jomon or the Yayoi period (i.e. before 300 A.D.) (Kasahara 1976) (Table 1).

There are a number of other plant species which are putatively prehistoric invaders of Japan (Maekawa 1943) but for which no archeological evidence has been cited (Table 2).

Table 1. Prehistoric exotic invaders of Japan that also have invaded south eastern Australia.

ASTERACEAE
Sonchus oleraceus L.*

BRASSICACEAE
Capsella bursapastoris (L.) Medik.

LAMIACEAE
Lamium amplexicaule L.

POACEAE
Poa annua L.

*'*S. oleraceus*' was noted by early botanists in Australia (including Cunningham) (D. Benson pers. comm., 2002).

Table 2. Putative prehistoric exotic invaders to Japan that have also invaded south eastern Australia.*

ASTERACEAE
Bidens tripartita L.
Eclipta prostrata (L.) L.

CYPERACEAE
Cyperus difformis L.
Cyperus rotundus L.

POACEAE
Cynodon dactylon (L.) Pers.
Digitaria ciliaris (Retz.) Koeler
Eleusine indica (L.) Gaertn.

POLYGONACEAE
Polygonum aviculare L
Polygonum hydropiper L.

PORTULACACEAE
Portulaca oleracea L.

SOLANACEAE
Solanum nigrum L.

*Perhaps as prehistoric invaders.

The routes of the early invading plants are thought to have been from Eurasia through China and the Korean peninsula and from South East Asia with the spread of shifting cultivation agriculture (slash and burn).

In Australia there are a few probable exotic species that are thought to have invaded before European settlement, such as *Acacia farnesiana* (L.) Willd. and there is good evidence that *Tamarindus indica* L. was introduced by Macassan traders to northern Australia in the eighteenth century (Macknight 1976).

Invasions since the 18th and 19th centuries

Following the arrival of Europeans in Australia in 1788, new plant species began to arrive in considerable numbers both intentionally and accidentally. By 1804, 29 species of introduced plants were collected around Sydney by Robert Brown (Groves 1986, 2002). In Brown's list first published in Britten (1906), the well-known plants *Anagallis arvensis* L., *Cynodon dactylon* (L.) Pers. (*Panicum dactylon* L.), *Euphorbia peplus* L., *Plantago major* L., *Poa annua* L. and *Stachys arvensis* L. were included. The numbers of new species to become naturalised in eastern and southern Australia have been estimated to have increased approximately linearly with time (Specht 1981). However Groves (2002) has shown that while the rate of naturalisation of plant species in the Sydney region has remained at a constant linear rate, the rate for naturalisation of plants in New South Wales increased sometime after 1893. The total number of alien plants in Australia was estimated to be about 2000 in 1994 (Michael 1994). Current estimates of the number of naturalised plant taxa in New South Wales and Australia based on vouchered herbarium specimens are 1564 and 2795 respectively (J. Hosking pers. comm., cited by Groves (2002).

Although the beginning of the Meiji period saw increased contact between Japan and other countries only some 25 new species were naturalised by the end of the Meiji period in 1910. Another 88 species had arrived by 1931, but most of the naturalised plants in Japan arrived after the second world war. The USA occupied Japan from 1945 to 1952 (USA military personnel are still present in several locations in Japan) but the rate of new incursions has continued at a constant logarithmic rate since the 1950's (Enomoto 1999). Of these, Enomoto (1998) listed 1195 species of naturalised plants from 105 families plus 3 subspecies, 69 varieties and 6 hybrids as weeds. Asai (1993) suggested that many weeds arrived as contaminants of wheat and soybeans imported from North America to alleviate food shortages after World War II.

Thus the total number of alien plants is similar in Japan and south eastern Australia but the time of arrival of most is more recent in Japan. Their arrival coincided with a period of rapid economic growth with the construction of highways and extension of the railway system providing corridors of disturbance for invasive plants. Appendix 1 lists the common exotic species that have invaded Japan (since the mid-nineteenth century) and south eastern Australia (since 1788) and become naturalised. This list includes species which have spread to the point where they are conspicuous and often troublesome but it does not include all naturalised species. There are some 187 species, from 36 plant families. Among these, 72 species are now widespread (see* Appendix 1) in both countries. The sources for this table include Asai (1993), Auld and Medd (1997), Kurokawa (2001), Harden (1990–2003), Ito and Morita (1999), Morita (1997), Rozefelds et al. (1999) Shimizu, Morita and Hirota (2001), Stanley and Ross (1983–1989), Walsh and Entwisle (1994–1999) and field observations by the authors. Apart from pasture grasses such as *Dactylis glomerata* and pasture legumes such as *Trifolium* species, most of these common invading species are regarded as weeds throughout the world (Holm et al. 1979). *Lilium formosanum*, a native of Taiwan, appears to be restricted to Japan, Australia and South Africa (Henderson 2001) as an invading species.

The weedy plant families Asteraceae (39 species) and Poaceae (34 species) are the most strongly represented (Appendix 1). In the Asteraceae annuals out-number perennials by two to one, but in the grasses they are in about equal numbers. Some of these weedy species have been deliberately planted in Japan such as *Vulpia myuros* for green mulch in orchards and *Eragrostis curvula* as a roadside cover species. Many species were originally planted as ornamentals in both countries (e.g. *Mirabilis jalapa*). Some species that are invasive in eastern Australia do not appear to have escaped cultivation in Japan, including *Tradescantia fluminensis* Vell. (*Tradescantia albiflora* Kunth).

Most of these invasive species originated from either the broad regions of Europe/Mediterranean/ Eurasia or the Americas. Five species are of South African origin and only two, *Persicaria capitata* and *Lilium formosanum* are from eastern Asia.

Euchiton sphaericus (Willd.) Anderb. (syn. *Gnaphalium sphaericum* Willd.), usually considered native in Australia, occurs in Taiwan and may extend to Japan (Michael 2001). There are several other Australian native species that are weeds in eastern Australia and could prove invasive in Japan such as *Poa labillardieri* Steud. and *Urtica incisa* Poir.

Threats to Australia

Of the naturalised floras in both countries, there is only a relatively small number of other widespread, invasive species in either Japan or eastern Australia. Given that there is so much in common in the invasive floras, one is drawn to consider the potential threat that these other exotic invaders in Japan may pose for Australia and vice versa.

Some 15 widespread exotic weeds in Japan have not been recorded as naturalised in Australia (Table 3).

While some of these species appear to be troublesome only in Japan, such as *Rudbeckia laciniata*, several such as *Bidens frondosa*, *Erechtites hieracifolia* and *Erigeron annuus* are widespread and could invade from several sources.

There are some native Japanese plants that have become troublesome as weeds in Japan that have not been recorded in Australia; in particular, the following species which spread by subterranean vegetative organs: *Metaplexis japonica* (Thunb.) Makino, Asclepiadaceae; and *Petasites japonicus* (Siebold & Zucc.) Maxim., Asteraceae. One such species, *Reynoutria japonica* Houtt., Polygonaceae, has been planted apparently as an ornamental and recently escaped cultivation in south eastern Australia.

Since Australia does not generally import unprocessed agricultural produce from Japan, it is more likely that any Japanese plants that may become weeds in Australia would arise from species that were introduced as ornamentals (Table 4). Other relevant factors would include their capacity to spread e.g. by berry fruits which were attractive to birds and attributes such as shade tolerance; Senryo, *Chloranthus glaber* (Thunb.) Makino, Chloranthaceae, is an example.

Table 3. Widespread weeds in Japan of recent (after mid 19th century) exotic origin which have not been recorded as naturalised in Australia and their quarantine (Q) status in Australia (see below).

ASTERACEAE
Ambrosia trifida L.
prohibited Q
Bidens frondosa L.
Erechtites hieracifolia (L.) Raf. ex DC.
Erigeron annuus (L.) Pers.
prohibited Q
Erigeron philadelphicus L.
Galinsoga quadriradiata Ruiz & Pavon
Rudbeckia laciniata L.
prohibited Q
Solidago gigantea Ait.
var. *leiophylla* Fernald

BRASSICACEAE
Barbarea vulgaris R.Br.
permitted Q

CONVOLVULACEAE
Ipomoea coccinea L.

CUCURBITACEAE
Sicyos angulatus L.

GERANIACEAE
Geranium carolinianum L.

LYTHRACEAE
Ammannia coccinea Rottb.
prohibited Q

SCROPHULARIACEAE
Lindernia dubia Penn.

SOLANACEAE
Solanum carolinense L.
prohibited Q

Q: The Australian Quarantine and Inspection Service (AQIS) assesses each request to import plants to Australia. If a species is considered a potential weed in Australia it will be prohibited from importation. If an application has already been made for the importation of a species, the status of that species in terms of quarantine can be found on the AQIS web site from the AQIS Import Conditions (ICON) database (http://www.aqis.gov.au/icon/). If a species is not on the database it means that there has been no previous assessment of it because there has been no request to import it. It does not mean that the species is not prohibited from entry.

Table 4. Ornamentals from Japan, not naturalised in Australia

Scientific name (Family)	Japanese name	English name
Aucuba japonica Thunb. (CORNACEAE)	Aoki	Japanese Aucuba
Enkianthus campanulatus (Miq.) G. Nicholson (ERICACEAE)	Sarasa-dodan	Redvein Enkianthus
Eurya japonica Thunb. (THEACEAE)	Hisakaki	
Callicarpa japonica Thunb. (VERBENACEAE)	Murasaki-shikibu	Japanese beauty berry

Some Japanese native plants have become weeds in Australia and these were presumably deliberately introduced e.g. *Lonicera japonica* Thunb. and the trees *Celtis sinensis* Pers. and *Cinnamomum camphora* (L.) J.Presl. The latter, a native of the island of Kyushu, has spread from deliberate plantings in Japan beyond its 'natural' range as many *Acacia* species have done in Australia.

Several other ornamentals from Japan do not appear to have escaped cultivation although *Ardisia crenata* Sims, coral or spice berry is listed as a potential invader by Randall (2001), is now naturalised in NSW and Qld.

Anomalies and threats to Japan

There are a number of species that are major weeds in eastern Australia and although naturalised in Japan are not yet widespread or invasive. Surprisingly this group includes *Carthamus lanatus* L., *Parthenium hysterophorus* L., *Marrubium vulgare* L. and *Urtica urens* L.

A noticeable feature of the invasive flora in mainland Japan is the lack of woody species and invaders of forest areas. *Cytisus scoparius* (L.) Link, *Ulex europaeus* L., *Ligustrum lucidum* W.T. Aiton, a native of China and *Pyracantha angustifolia* (Franch.) C.K. Schneid. are all naturalised in Japan but not yet widespread or invasive as they are in eastern Australia. *Robinia pseudoacacia* L. is one of the few invasive trees on mainland Japan (Maekawa and Nakagoshi 1997) although in Australia it often only occurs as a relic in areas around animal yards where it was planted.

Rubus fruticosus agg. (Appendix 1) although invasive in Japan is not nearly so widespread and troublesome as it is in Australia. However the taxa naturalised in Japan may differ from those in Australia. It is only one of several woody shrubs that are important weeds in Australia which could become major problems in forests and on forest margins in Japan. The common pink *Lantana camara* L. *sens. lat.* is still sold as an ornamental in Japan. *Baccharis halimifolia* L. and *Ageratina adenophora* (Spreng.) R.M. King & H. Rob. have not yet been recorded in Japan, although the latter is a weed in Thailand, China and Vietnam.

The reason for the lack of impact of exotic woody species in Japanese forests and forest margins is intriguing. It may simply be that there has been insufficient time (< 50 years) for their populations to build up to conspicuous proportions. Moreover as the current populations of invaders are small, there may also be some degree of tolerance of their presence in the landscape.

Another factor that may contribute to resistance to invasion of forested areas is the allelopathic effects of the resident trees. Ito et al. (2002) recently demonstrated the allelopathic influence of soil collected from under several tree species in Japan.

Generalisations

There has been an increasing interest in and analyses of plant invasions in the last 20 years. These overviews (see Rejmanek (2001) for a succinct account) have yielded few useful general rules for predicting future invasions. The most robust of these is that a history of invasion of a species in one location indicates a greater likelihood of invasion in another location: the 'historical' or 'extrapolation' approach. The observations reported here broadly support that generalisation with some apparent anomalies (above).

Another two fairly safe general predictors are that with increasing time since introduction and number of introductions, the rate of invasion for a species will increase; the 'stochastic' approach. The former is clearly implicated in the lack of impact of woody species, some of which have a long juvenile period, in Japan to this point in time. Increasing number of introductions is most likely to occur with ornamentals and forest species. Several Australian native woody species have become weeds as a consequence of massive, widespread, deliberate plantings, particularly in South Africa (Henderson 2001). The majority of the invasive successes of these species can be ascribed to chance. It is simply that their chances of establishing beyond the area in which they were planted have been markedly increased by the huge numbers and geographic extent of their deliberate plantings. These cases are in stark contrast to the epidemic spread of some weed species, such as *Parthenium hysterophorus* in Australia (Auld, Hosking and McFadyen 1983), which have invaded widely without deliberate involvement of humans.

The subsequent invasive spread of exotic species from massive, deliberate ornamental and forestry plantings around the world presents a strong case for care in horticultural plantings and the use of sterile plants in forest plantations. The latter could provide a broadly acceptable role for genetically modified plants in the environment.

Resisting invasion

In Australia, in spite of an active quarantine service, invasions will continue via accidental and illegal introductions and also by approved routes because of the difficulty of predicting invasive species. Changes in land use, for instance, will create new habitats that may favour particular species that might otherwise have remained benign. However as noted above, the rate of invasion of exotic species to Australia has been roughly linear while in Japan it has been logarithmic.

In Japan, quarantine laws address insects, soil, plant diseases and parasitic plants. There are no restrictions on the importation of exotic plants *per se*. Thus there will be a continuing influx of deliberately introduced exotics for ornamental and other purposes as well as contaminants of crop seeds and fodder. Japan imports in excess of 15 million tonnes of fodder and 2.5 million tonnes of roughage per annum from all over the world. A study of the contaminants of fodder crop imports at Kashima port from September 1993 to November 1994 has been reported by Enomoto (1999) and Nishida and Shimizu (1999). Of 105 samples from 10 different countries, only one sample contained no weed seeds. Among the other 104 samples there were 1482 different forms of seeds. One sample of rye from Finland contained 39 weed species and a sample of buckwheat from China contained 36 weed species (Nishida and Shimizu 1999).

These findings make a strong case for quarantine laws to restrict the incursion of unwanted exotic plants in Japan (Ecological Society of Japan, 2002). Moreover, the threat that some species, already in Japan, may pose to the Japanese landscape should be considered.

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Appendix 1. Invading plant species (mostly regarded as weeds) common to Japan and eastern Australia that are exotic to both countries.

*Species that are widespread in both countries are marked with an asterisk. These generally occur over more than 4 degrees of latitude, may occur in more than one habitat type and are often locally abundant in at least one habitat in both countries.

Amaranthaceae
Alternanthera philoxeroides (Mart.) Griseb.
Amaranthus albus L.
**Amaranthus hybridus* L.
**Amaranthus retroflexus* L.
**Amaranthus spinosus* L.
**Amaranthus viridis* L.
Gomphrena celosioides Mart.

Apiaceae
Ammi majus L.
**Cyclospermum leptophyllum* (Pers.)Sprague ex Britton & P.Wilson (*Apium leptophyllum* (Pers.) F.Muell. ex Benth.)
Conium maculatum L.

Araceae
Pistia stratiotes L.

Asteraceae
**Achillea millefolium* L.
Ageratum conyzoides L.
Ambrosia artemisiifolia L.
Ambrosia psilostachya DC.
**Anthemis cotula* L.
Arctotheca calendula (L.) Levyns
Aster novi-belgii L.
**Aster subulatus* Michx.
**Bidens pilosa* L.
Centaurea calcitrapa L.
Cichorium intybus L.
Cirsium arvense (L.) Scop.
**Cirsium vulgare* (Savi) Ten.
**Conyza sumatrensis* (Retz.) Walker (*C. albida* Willd. ex Spreng.)
**Conyza bonariensis* (L.) Cronquist
Conyza canadensis (L.) Cronquist
**Coreopsis lanceolata* L.
Facelis retusa (Lam.) Sch.Bip.
**Galinsoga parviflora* Cav.
**Gamochaeta calviceps* (Fernald) Cabrera
Gamochaeta pensylvanicum (Willd.) Cabrera
Gamochaeta spicata (Lam.) Cabrera (syn. *Gnaphaluim coarctatum* (Willd.) Cabrera)

Helianthus tuberosus L.
*_Hypochoeris radicata_ L.
*_Leucanthemum vulgare_ Lam.
Pseudognaphalium luteo-album (L.) Hillard & B.L. Burtt
Schkuhria pinnata (Lam.) Kuntze ex Thell. var. _abrotanoides_ (Roth) Cabrera
Senecio madagascariensis Poir.
Senecio vulgaris L.
Silybum marianum (L.) Gaertn.
Solidago altissima L.
Solidago canadensis L.
*_Sonchus asper_ (L.) Hill
Tagetes minuta L.
*_Taraxacum officinale_ Webber ex F.H. Wigg. agg.
Tragopogon porrifolius L.
Xanthium italicum Moretti
*_Xanthium occidentale_ Bertol.
Xanthium spinosum L.

Boraginaceae
Amsinckia lycopsoides Lehm.
Buglossoides arvense (L.) I.M.Johnst.
Echium plantagineum L.
Heliotropum indicum L.

Brassicaceae
*_Brassica juncea_ (L.) Czern.
Cakile edentula (Bigelow) Hook.
Cardamine hirsuta L.
*_Lepidium bonariense_ L.
Lepidium campestre (L.) R.Br.
Lepidium draba L. (_Cardaria draba_ (L.) Desv.)
*_Lepidium didymum_ L. (_Coronopus didymus_ (L.) Sm.)
Raphanus raphanistrum L.
Sinapis alba L.
Sisymbrium irio L.
*_Sisymbrium officinale_ (L.) Scop.
*_Sisymbrium orientale_ L.
Thlaspi arvense L.

Caryophyllaceae
*_Cerastium glomeratum_ Thuill.
Petrorhagia nanteuilii (Burnat) P.W.Ball & Heywood
*_Polycarpon tetraphyllum_ (L.) L.
*_Sagina procumbens_ L.
Saponaria officinalis L.
*_Silene gallica_ L. var. _quinquevulnera_ (L.) Koch
Silene vulgaris (Moench) Garcke
*_Spergula arvensis_ L.
*_Stellaria media_ (L.) Vill.
Vaccaria hispanica (Mill.) Rauschert

Chenopodiaceae
*_Chenopodium album_ L.
*_Chenopodium ambrosioides_ L.
Chenopodium murale L.

Clusiaceae
*_Hypericum perforatum_ L.

Convolvulaceae
*_Convolvulus arvensis_ L.
Cuscuta campestris Yunck.
Ipomoea cairica (L.) Sweet
Ipomoea purpurea (L.) Roth
Ipomoea triloba L.

Cyperaceae
*_Cyperus eragrostis_ Lam.
*_Cyperus esculentus_ L.

Euphorbiaceae
Euphorbia peplus L.

Fabaceae
*_Lotus corniculatus_ L.
Lotus uliginosus Schkuhr
Medicago arabica (L.) Huds.
*_Medicago lupulina_ L.
Medicago minima (L.) Bartal.
*_Medicago polymorpha_ L.
*_Medicago sativa_ L.
Melilotus albus Medik.
Melilotus indicus (L.) All.
Melilotus officinalis (L.) Lam.
Robinia pseudoacacia L.
Trifolium angustifolium L.
Trifolium arvense L.
*_Trifolium campestre_ Schreb.
*_Trifolium dubium_ Sibth.
Trifolium fragiferum L.
Trifolium glomeratum L.
Trifolium hybridum L.
*_Trifolium pratense_ L.
*_Trifolium repens_ L.

Fumariaceae
Fumaria officinalis L.

Gentianaceae
Centaurium erythraea Raf.

Geraniaceae
*_Erodium cicutarium_ (L.) L'Hér.
Erodium moschatum (L.) L'Hér.

Lamiaceae
Salvia reflexa Hornem.
Stachys arvensis (L.) L.

Liliaceae
Lilium formosanum Wallace

Lythraceae
Lythrum hyssopifolia L.

Malvaceae
Hibiscus trionum L.
*_Malva parviflora_ L.
Modiola caroliniana (L.) G.Don
Sida acuta Burm.f.
Sida rhombifolia L.
Sida spinosa L.

Nyctaginaceae
Mirabilis jalapa L.

Onagraceae
Oenothera stricta Ledeb. ex Link

Orobanchaceae
Orobanche minor Sm.

Oxalidaceae
Oxalis bowiei Aiton ex G. Lodd. (_O. bowieana_ G.Lodd.)
Oxalis brasiliensis G.Lodd.
*_Oxalis debilis_ Kunth _var. corymbosa_ (DC.) Lourteig (_O. corymbosa_ DC.)
Oxalis pes-caprae L.

Papavaceae
Papaver dubium L.

Passifloraceae
Passiflora foetida L.

Phytolaccaceae
Phytolacca americana L.

Plataginaceae
*_Plantago lanceolata_ L.
Plantago major L.

Poaceae
*_Elymus repens_ (L.) Gould (_Agropyron repens_ (L.) P.Beauv.)
*_Andropogon virginicus_ L.
*_Anthoxanthum odoratum_ L.
Arrhenatherum elatius (L.) J.&C. Presl
*_Avena fatua_ L.
Briza maxima L.
Briza minor L.
*_Bromus catharticus_ Vahl
Bromus hordeaceus (L.) ssp. _molliformis_ (Jn.Llyod ex Godr.) Maire & Weille
Bromus rigidus Roth
Bromus rubens L.
Cenchrus echinatus L.
Chloris gayana Kunth
Chloris virgata Sw.
Cortaderia selloana (Schult. & Schult.f.) Asch. & Graebn.
*_Dactylis glomerata_ L.
*_Eragrostis curvula_ (Schrad.) Nees
*_Holcus lanatus_ L.
Lolium multiflorum Lam.
Lolium perenne L.
Lolium rigidum Gaudin
Melinis repens (Willd.) Zizka (_Rhynchelytrum repens_ (Willd.) C.E.Hubb.)
Panicum maximum Jacq.
Paspalum conjugatum P.J.Bergius
*_Paspalum dilatatum_ Poir.
*_Paspalum distichum_ L.
*_Paspalum urvillei_ Steud.
Pennisetum purpureum Schumach.
Phalaris canariensis L.
Phalaris minor Retz.
Phalaris paradoxa L.
Poa bulbosa L.
*_Sorghum halepense_ (L.) Pers.
*_Vulpia myuros_ (L.) C.C.Gmel.

Polygonaceae
*_Acetosella vulgaris_ Fourr.
Persicaria capitata (Buch.-Ham. ex D.Don) H.Gross
*_Rumex conglomeratus_ Murray
*_Rumex crispus_ L.
*_Rumex obtusifolius_ L.

Pontederiaceae
Eichhornia crassipes (Mart.) Solms

Ranunculaceae
*_Ranunculus muricatus_ L.

Rosaceae
Rubus fruticosus L. agg.

Scrophulariaceae
*_Verbascum thapsus_ L.
Verbascum virgatum Stokes
*_Veronica arvensis_ L.
*_Veronica persica_ Poir.

Solanaceae
Datura ferox L.
*_Datura stramonium_ L.
*_Nicandra physalodes_ (L.) Gaertn.
Solanum rostratum Dunal

Verbenaceae
Verbena bonariensis L.
Verbena litoralis Kunth

FORUM:

Pittosporum undulatum as a case study for native species that change range – how to avoid inappropriate responses?

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Abstract: During the past two centuries massive land use changes in Australia have altered fire regimes, changed hydrology, increased soil salinity and nutrient levels, and altered abundance and distributions of animals with which native plants interact. Such changes to plant habitats may induce changes in range of indigenous plant species. We need to consider very carefully how to treat native species that naturalise outside their previous ranges. The spread of *Pittosporum undulatum* in the Sydney region provides a case study for considering approaches to this question.

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Introduction

Pittosporum undulatum Vent. (family Pittosporaceae), known as Sweet Pittosporum or simply Pittosporum, is a small tree native to certain moist forests and woodlands on fertile soils on the coast and nearby ranges in southeastern Australia. Its natural range extends from southern Queensland (Bailey 1899) to eastern Victoria. At the western end of its range it was recorded 'in rocky places about Western Port' by Mueller in 1860 (Bentham & Mueller 1863). In recent years, concern about its spread particularly in Victoria (e.g. Gleadow & Ashton 1981) has seen it branded as an 'environmental weed' for the whole of southeastern Australia (e.g. Blood 2001, Mullett 2000). It is also now reported as a weed in South Australia, Tasmania and Western Australia, presumably as a consequence of horticultural plantings (Blood 2001). However, in the Sydney region, calling it a weed has put at risk scarce remnants of vegetation where it is native.

Natural range of Pittosporum undulatum *in the Sydney area*

In the greater Sydney Basin Bioregion, *Pittosporum undulatum* occurs naturally in widespread sandstone gully habitats, and in the understorey of two very rare vegetation types, Blue Gum High Forest and Sydney Turpentine Ironbark Forest, that have been greatly reduced compared with their former extent (Benson & Howell 1990). Each has been listed an Endangered Ecological Community under the NSW *Threatened Species Conservation Act* 1995. Much of the area remaining of each endangered forest, especially of Sydney Turpentine Ironbark Forest, persists as small patches on edges of privately-owned farmland (e.g. Smith & Smith 1990).

Range extension in the Sydney area is related to human-induced habitat changes

Many native plants have suffered reductions in range as a result of European settlement, yet that of *Pittosporum undulatum* appears to be expanding. Although Pittosporum's natural shale soil habitats in Sydney have been mostly cleared and settled, increased moisture and soil nutrients run off settled areas on shale into adjacent bushland on sandstone, making edges of this previously infertile habitat suitable for it. As it has colonised this changed habitat, *Pittosporum undulatum* has been reported as invading bushland on sandstone (Buchanan 1989a) and potentially reducing biodiversity on these sites (Brown et al. 1991, Mullett & Simmons 1995).

However, this invasion only extends as far as humans have modified the edges of the sandstone habitat (Rose 1997a, Rose & Fairweather 1997, Leishman 1990) with

- increased soil moisture and nutrients in run-off from farms and gardens, and
- reduced fire frequency close to settled areas.

Fire is known to stimulate germination of soil-stored seed of many understorey species in bushland on sandstone. Pittosporum seed germinates without light and fire, and, once established, Pittosporum's dense foliage tends to suppress growth of shrubs and herbs beneath (Gleadow 1982). Normally Pittosporum plants would be killed by periodic fires but reduced fire frequency in its natural shale and sandstone gully habitats has also allowed it to increase in abundance there (Buchanan 1991).

European settlement has also increased the abundance of birds that disperse Pittosporum's fruits and therefore aid its spread into bushland on sandstone where soil is sufficiently fertile. Pittosporum seed is dispersed by birds, including native Pied Currawongs, *Strepera graculina* (Buchanan 1989b) which have been favoured by urban gardens (Major et al. 1996), and introduced European Blackbirds, *Turdus merula* (Gleadow 1982). Under natural conditions the frequency of fruit-dispersing birds would have been low in vegetation on infertile sandstone soils, as the proportion of fleshy-fruited plant species there is small (Westoby et al. 1990).

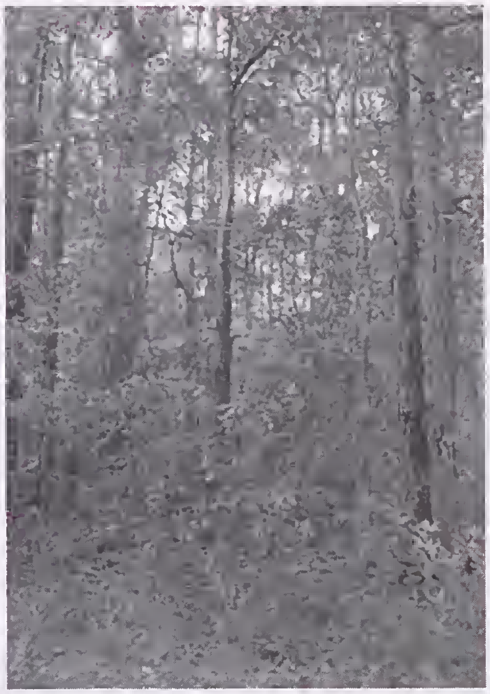

Fig. 1a. Sydney Turpentine Ironbark Forest with *Pittosporum undulatum* in the understorey

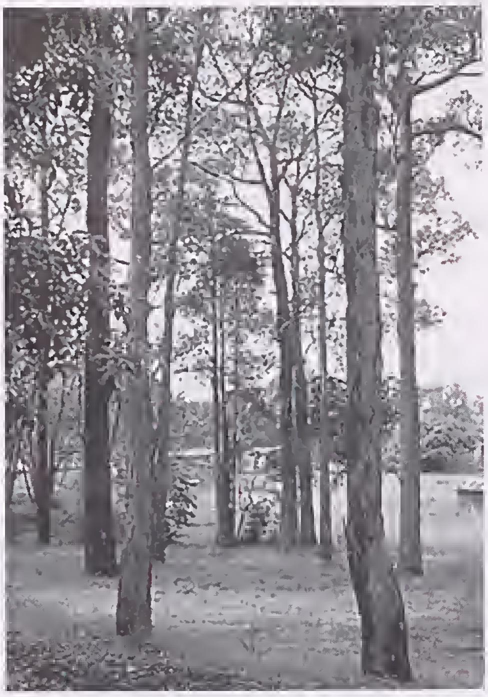

Fig. 1b. Understorey containing *Pittosporum undulatum* was cleared from this nearby Sydney Turpentine Ironbark Forest remnant on private land.

The result of these changes has been Pittosporum's expansion into adjoining, previously-unsuitable habitat. *Pittosporum undulatum* is not a weed in the Sydney context although it may grow inappropriately vigorously in some situations. Other native 'habitat-intruders' include the small trees *Glochidion ferdinandi* and *Omalanthus populifolius,* both in the family Euphorbiaceae (Buchanan 1989a), and the fern *Pteridium esculentum.* This type of gradual range extension may be analagous to what can be expected of some species in response to the changes in temperature, rainfall and other factors induced by climate change, and to other impacts such as changed fire regimes and increased soil moisture and nutrient status associated with European land use generally.

Discussion

In attempts to discourage planting and stop nurseries selling it, *Pittosporum undulatum* has been branded an 'environmental weed' (e.g. Walsh & Entwisle 1996, Mullett 2000, Blood 2001). This message, originating from research in Victoria (e.g. Gleadow & Ashton 1981, Mullett & Simmons 1995), though geographically appropriate in Victoria, has been widely circulated beyond there, including in guidelines for bushland management distributed at the local council level. I would like to draw attention urgently to adverse implications for biodiversity conservation arising from Pittosporum's dual native and weedy status in the Sydney region, and implications for other indigenous species that may extend their distributions elsewhere.

Members of the general public often don't understand any subtleties in the term 'environmental weed' — the message they receive is that Pittosporum is a weed that's bad for the environment, and should be eliminated! If they see it growing, even in scarce remnants of its native habitat, they are likely to get out the bulldozer and clear the whole understorey and all its associated biodiversity (Figure 1). This has been observed, with understorey of the Endangered Ecological Community Sydney Turpentine Ironbark Forest containing *Pittosporum undulatum* which has been bulldozed, clearing away other plant species, fauna associated with them, lichens, fungi, rootstocks, soil-stored seeds, associated mycorrhizas, other soil microorganisms and microfauna. Landowners may think they are doing the right thing, because of statements referring to 'the environmental weed *Pittosporum undulatum*'. Less well-intentioned people may use Pittosporum's presence as an excuse to get rid of bushland. Pittosporum itself looks set to survive as a species, but other biodiversity in scarce forest where it occurs may well be lost.

The current response to Pittosporum's increase in the Sydney area provides examples of potentially inappropriate responses that should be avoided in dealing with future range changes of native species. Labelling the species *Pittosporum undulatum* an 'environmental weed' and distributing this message widely has had unfortunate consequences. In addition to the threat to Endangered Ecological Communities described above, the idea that Pittosporum is a weed has become so entrenched that some bush regeneration contracts have specified its removal without follow-up treatment of affected areas. Results have included invasion of bared areas by exotic weeds such as *Lantana camara,* *Ehrharta erecta* and *Tradescantia fluminensis*, which cannot be considered an improvement to the habitat (R. Eckhard, P. Woodard pers. comm.). Simply removing Pittosporum without addressing other habitat changes, soil nutrient status and especially changed fire frequency, will not restore the former vegetation (Buchanan 1989a, Rose 1997b, Muyt 2001). Treated areas need fire to stimulate recruitment from the soil seedbank of shrubs and herbs that formerly occupied the site, and measures to prevent continuing addition of soil nutrients that favour Pittosporum.

Conclusion

In the case of *Pittosporum undulatum*, labelling it as a weed in order to prevent perceived loss of biodiversity has created a threat to other biodiversity. In order to counteract the effects of these past communications and prevent loss of rare forest types in Sydney, there is a need to

- Devise a strategy that conveys the message that *Pittosporum undulatum* is an appropriate native species within its original natural geographic range, (though it may be a habitat intruder in some places within this range), but that beyond this original geographic range it may behave as a weed in natural environments.
- Stop attaching a single label such as an 'environmental weed in southeastern Australia' to the species as a whole; specify precisely the location and conditions when discussing situations where it may be perceived as a problem invader.
- Use only ecologically qualified people to reduce its abundance where necessary as part of integrated management of native vegetation.
- Use, rather than abuse Pittosporum in its natural range, to suppress weeds and hazardous fuel growth on bushland edges!

In the case of other native species that may begin to change their ranges in response to human-induced modifications generally, I believe there is a need for more discussion on how such species should be treated. It is important to consider carefully how to communicate their status to the general public, particularly in view of the likely need for more plant species conservation to take place outside the current reserve system as distributions change in response to climate and other changes (Hughes & Westoby 1994). It is obvious from Pittosporum's example that native range-changers need to be treated on a case-specific and site-specific basis, rather than lumped into a group with a single label that may be misunderstood. In the face of land use and habitat changes, we will need to think laterally and creatively about how to describe and discuss these species in order to avoid causing loss of biodiversity due to inappropriate responses in the community.

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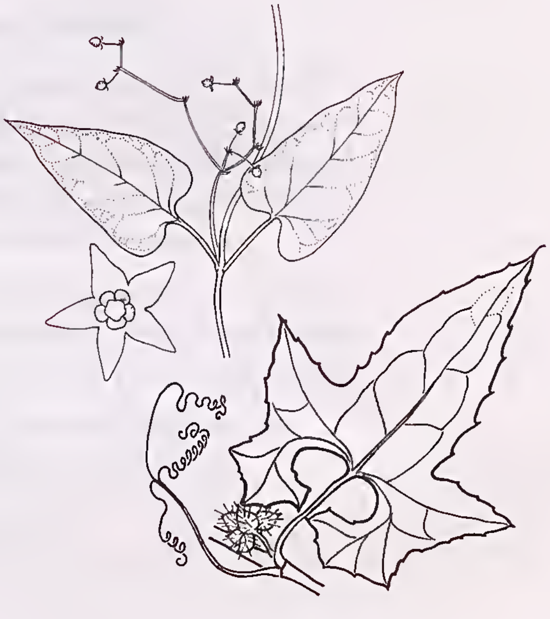

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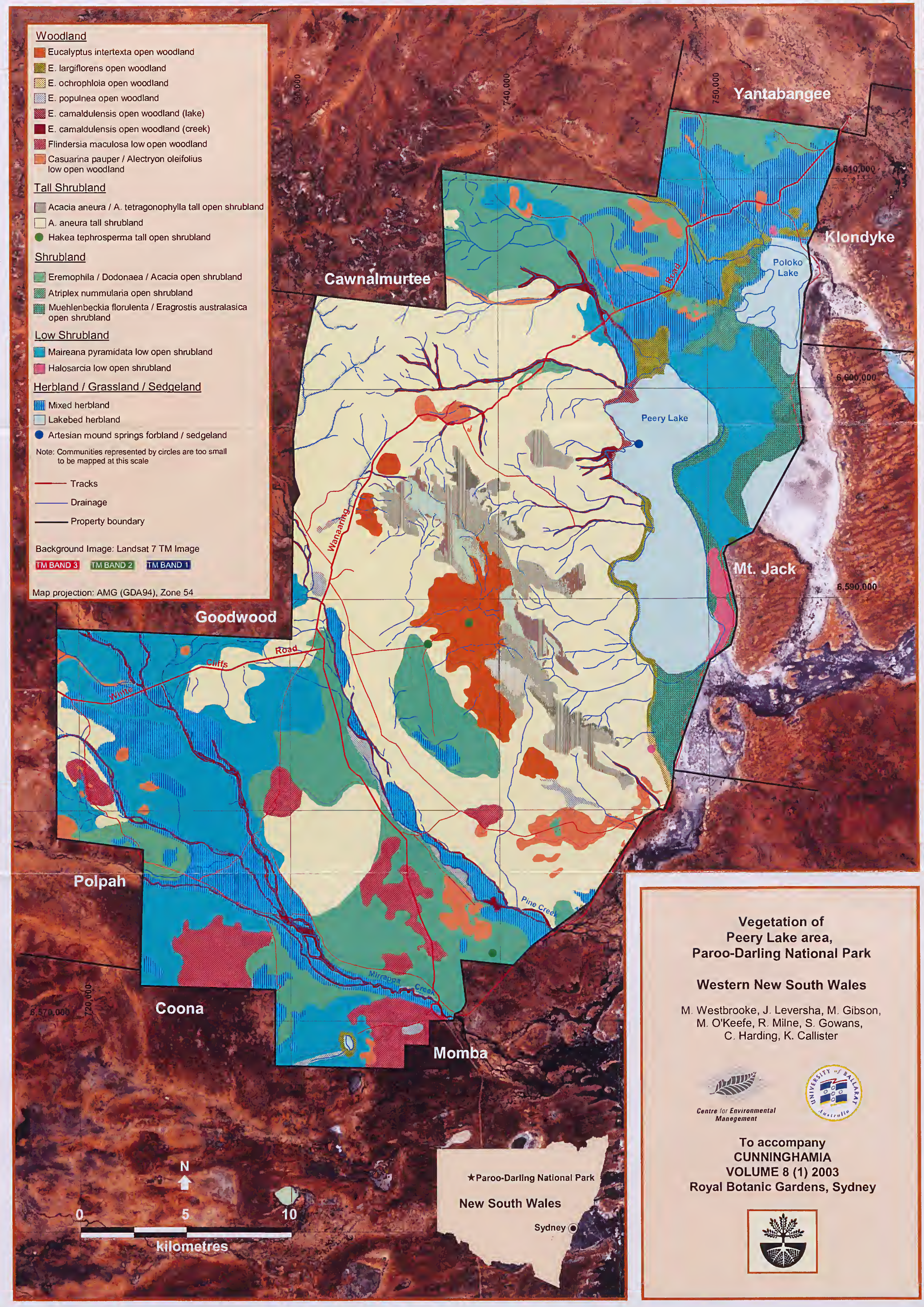

Woodland

- 🟧 Eucalyptus intertexta open woodland
- ▨ E. largiflorens open woodland
- ▨ E. ochrophloia open woodland
- ▨ E. populnea open woodland
- ▨ E. camaldulensis open woodland (lake)
- 🟥 E. camaldulensis open woodland (creek)
- ▨ Flindersia maculosa low open woodland
- 🟧 Casuarina pauper / Alectryon oleifolius low open woodland

Tall Shrubland

- ▥ Acacia aneura / A. tetragonophylla tall open shrubland
- ☐ A. aneura tall shrubland
- ● Hakea tephrosperma tall open shrubland

Shrubland

- 🟩 Eremophila / Dodonaea / Acacia open shrubland
- ▨ Atriplex nummularia open shrubland
- ▨ Muehlenbeckia florulenta / Eragrostis australasica open shrubland

Low Shrubland

- 🟦 Maireana pyramidata low open shrubland
- 🟥 Halosarcia low open shrubland

Herbland / Grassland / Sedgeland

- ▥ Mixed herbland
- ☐ Lakebed herbland
- ● Artesian mound springs forbland / sedgeland

Note: Communities represented by circles are too small to be mapped at this scale

- —— Tracks
- —— Drainage
- —— Property boundary

Background Image: Landsat 7 TM Image

TM BAND 3 TM BAND 2 TM BAND 1

Map projection: AMG (GDA94), Zone 54

Vegetation of Peery Lake area, Paroo-Darling National Park

Western New South Wales

M. Westbrooke, J. Leversha, M. Gibson,
M. O'Keefe, R. Milne, S. Gowans,
C. Harding, K. Callister

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